The Merced River Salmon Habitat Enhancement Project Robinson Reach (Phase III) 2004 Geomorphic Monitoring Report

California Department of Water Resources

San Joaquin District

River Management Section

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1 EXECUTIVE SUMMARY

This report summarizes the California Department of Water Resources geomorphic monitoring activities and data for the Robinson Reach of the Merced River Salmon Habitat Enhancement Project. Geomorphic monitoring began immediately after project construction ended in early 2002 and is on-going. This report covers monitoring and data through late 2004.

DWR undertook the monitoring work to document baseline conditions and initial changes in the physical characteristics of the 310 acre project site, and to test assumptions made during the project design process. This data will be used to improve and adapt the project's monitoring plans and our understanding of the processes acting on the reach, and ultimately, to apply this understanding to improve future design efforts.

Monitoring activities were designed to cover the project's 11,600 feet of channel and up to 1,600 feet of floodplain width in the best manner possible, subject to time, staffing, and financial constraints. Monitoring was based on several initial hypotheses that described how we expected the project site to respond following its construction. Activities fell into hydraulic, hydrologic, and geomorphic categories. Monitoring included topographic surveys, longitudinal and cross-sectional profile surveys, water surface elevation surveys, flow measurement, flow gage operation, bulk sample collection, bedload transport sample collection, pebble counts, tracer gravel studies, and aerial photograph comparisons. DWR established 32 monitoring cross-sections throughout the reach and used them as the data collection points for most of the activities. The resulting data is reported here primarily in graphical form.

Although this report is primarily meant to convey the data collected, findings based on some basic analyses are also presented. Using the data resulting from the activities listed above, we calculated channel changes over the monitoring period, conducted some sediment transport analyses, and created a low-flow one-dimensional hydraulic model of the reach. Because flows did not exceed design bankfull for any significant amount of time during this period of monitoring, no major changes in the channel were observed. However, monitoring data did show several significant trends and characteristics of the channel's performance in that period of time. One conclusion reached from the data is the suggestion that bed material in the constructed channel was more mobile during the first year after construction than in the subsequent year, even though flows in the second year were slightly higher. In addition, data show deposition in pool/bend sections of the reach. This, along with evidence of sub-bankfull bed mobility, suggests that these sections are narrowing to increase their ability to transport the sediment delivered to them.

Based on the data collected and results of analyses, report recommendations include modifications to the original hypotheses, additional questions to answer through monitoring activities, and proposed future monitoring activities. We also list other proposed studies for the project site based on additional hypotheses.

2 INTRODUCTION

Construction of the Robinson Reach of the Merced River Salmon Habitat Enhancement Project was completed in February 2002. On completion of this ambitious project, encompassing reconstruction of more than two river miles of channel and floodplain, an equally daunting task was presented: monitoring of the project site to gain an understanding of the geomorphic processes at work, and to improve future maintenance of the site and future design of other projects.

During the ensuing years, the California Department of Water Resources has used various data collection techniques on the project site to obtain the data needed to monitor the progress and condition of the site. The purpose of this paper is to present the data collected from 2002 through late 2004 and to offer some basic analyses of the data. In addition, we will make suggestions for future directions of monitoring efforts.

Information in this report is organized with a background section describing the project and the monitoring plan, an activities section that describes each of the activities in detail, and a data section that presents the data through tables and figures. Each of the sections is organized with text and tables coming first, and all figures following at the end of the sections. At the end of the report we present a summary as well as future monitoring plans and suggested studies.

3 PROJECT DESCRIPTION

3.1 Project Location and History

The Merced River Salmon Habitat Enhancement Project (MRSHEP) consists of approximately 4 miles of the Merced River centered on the Highway 59 Bridge near Snelling, California (Figure 3.1.1). Originally titled the Robinson/Gallo Project, the reach was identified in the Comprehensive Needs Assessment report (DWR, 1994) as having a high restoration priority for much of its length, and preliminary design work was begun in 1995. Phase III (Robinson Reach) of the MRSHEP is located between river miles 42 and 44 just upstream of the Highway 59 bridge. It consists of reaches #1 and #2 of the MRSHEP (Figure 3.1.2) and an adjacent 2000 foot upstream reach. Both MRSHEP reaches were approved for initial funding in 1998 under the Delta Pumping Plant Fish Protection Agreement (Four Pumps), the CALFED Ecosystem Restoration Program, and the Department of Fish and Game (Proposition 70 Funds). Additional cost sharing funding was provided by Four Pumps, CALFED, USFWS Anadromous Fish Restoration Program, and others.

Before the flood event of January 1997, as much as 25 percent of Merced River's Chinook salmon spawning took place in the project reach (Pers. Comm. Bill Loudermilk, DFG, 1999). The 1997 floodwaters breached the mining berms that had confined the river to the historic channel; as a result, the river abandoned the historic channel in favor of a gravel pit that had been excavated approximately six feet deeper than the channel. When the river abandoned the channel, all of the spawning riffles and much of the existing nursery habitat were lost. After the river breached most of the berms during that event, for much of the reach it became a broad, flat, shallow and slow moving river. The flat portions lacked a defined channel and adequate alluvium in the bed, both of which are important elements in any functional alluvial stream. This situation interfered with the natural processes of the stream and created many barriers to salmon survival. The wide, flat, shallow area presented both stranding issues during flow fluctuation as well as increased avian predation of smolts. In-stream ponds provided habitat for predatory fish species and resulted in flow velocities being reduced.

DWR designed and engineered a solution to the problems the reach presented to both the Chinook salmon and the river function as a whole (DWR, 2001). Construction of the reach began on July 11, 2001, and was completed at the end of February, 2002 (DWR, 2002). During that time, the 310 acre site was transformed by the movement of approximately one million cubic yards of on-site material. It was redistributed to realign or modify 11,600 feet of river channel and create a floodplain 700 to 1,600 feet wide. To accomplish that task, several ponds were filled with up to ten feet of material borrowed from abandoned point bars, which were in turn excavated to floodplain elevation. In addition, 60,000 cubic yards of graded gravel, designed with the intent to be mobile in the design channel under the current flow regime, was produced on-site. The gravel was placed in the design channel on constructed point bars and riffles and in portions of the unmodified channel, and was also placed in a stockpile for future gravel augmentation use.

Immediately following the completion of construction, a revegetation plan (DWR, 2001) began to be implemented by DWR and DFG personnel. Oaks, willows, and other woody vegetation began to be planted on the floodplain and on terraces on the project site. Native grasses and barley were seeded throughout most of the floodplain as well in an effort to keep invasive species from gaining a foothold before revegetation efforts could be completed. Revegetation is a long term project that is still continuing to be implemented, monitored, and maintained.

3.2 Goals and Objectives of Project Implementation

The goal of the MRSHEP from an engineering perspective is to have a continuous and functional river over the entire reach, but the overarching goal of the project is to benefit the salmon of the Merced River (DWR, 2001). Project designers believe that by creating and enhancing a functional river, the overarching goal will be met.

The goal for Phase III of the project was to benefit the salmon of the Merced River by creating a more natural and functional reach with well defined channels and floodplains. Objectives included the following:

A. eliminate or isolate juvenile salmon predator habitat;

B. increase the quantity and quality of spawning habitat for Chinook salmon;

C. increase the quantity and quality of rearing habitat for Chinook salmon;

D. improve river and floodplain dynamics;

E. create and enhance the riparian corridor;

F. improve sustainability of the river;

G. improve the adult and juvenile migratory path.

Project designers strived to achieve these objectives through several features of the design. Predator habitat was eliminated by filling ponds, and the channel was reconfigured to improve spawning and rearing habitat for salmon. River and floodplain dynamics were improved by reconfiguring and scaling the channel to fit the post-dam flow regime. The design channel includes riffles, pools, and a meander that fits the approximate slope and design bankfull flow. Constructed floodplains have been replanted with native riparian vegetation and contain simulated abandoned channels and backwater channels for diversity. These features will lead to an enhanced riparian corridor, improved sustainability of the channel, and an improved migratory path for salmon through the reach.

3.3 Project Design Framework

Project design was based on recognized and established formulas and concepts that were used to guide the design of the floodway, channel planform, and channel shape parameters. The parameters were also developed under the assumption that initially simple channel design features would develop into more complex features over time. The MRSHEP Phase III Engineering Report (DWR, 2001) details how the reach hydrology, sediment transport characteristics, historical data, and empirical models were all used to come up with a project design that not only meets the goals and objectives of the project, but also helps the river to once again become a sustainable and functional riparian ecosystem.

The components of the engineered portion of the design can be broken up into the three parameters mentioned above. Floodway parameters include the floodway slope and width, as well as features found within the floodway such as Simulated Abandoned Channels, backwaters, and ponds. While the latter features can be based on historical photos and topographic maps, the slope and width of the floodway depend on the existing topography and project area of the reach. The width of the reach was determined by including all existing or potential river bottom area, which included existing and abandoned channel, ponds, and unfarmed terraces. The slope depended on several factors: pre-project valley slope, upstream and downstream transition water surfaces, and the amount of fill material available to the project. By balancing these factors, designers came up with a design with four reaches, each with a different design valley slope. It would have been much simpler to have one slope throughout, but the deciding factors included the existing slopes that were influenced by historic aggregate mining and the lack of fill material available to raise elevations for portions of the reach.

The channel planform design, which includes parameters (Figure 3.3.1) such as the sinuosity, meander length, belt width, radius of curvature, and channel slope, depended largely on the established floodway slopes, historical sinuosity, and empirical equations. Because most of the equations relate to channel width, that dimension was initially assumed using the channel width of the previous phase of the project (Phase II), although it was later fine-tuned as one of the channel geometry characteristics. The Phase II channel width was based on hydraulic calculations, reference reach observations, and analysis of published estimates. Most of the planform design parameter calculations resulted in ranges of acceptable values, so a “best fit” was chosen based on observed values and the valley slopes, material size, and geographical constraints. In developing the channel features for a river with a bankfull flow only 1/3 the magnitude of the pre-dam flow, new values for meander length (1,450 ft), amplitude (360-1,480 ft), and radius of curvature (350 ft) were used in the design.

The last design step was to develop the channel geometry characteristics. The width, depth, slope, and shape of the riffles and pools depended largely on average channel slopes and resultant velocities, depths, and sediment transport capability. Using an analysis of the hydrology of the reach (originally done for Phase II, DWR, 2000) to determine target flows for spawning (225cfs), bankfull (1,700cfs), and flood flows (8,000cfs) in the reach, channel geometry was developed based on hydraulic and sediment transport calculations. Target velocities and depths for both spawning and sediment transport were met through variation of the channel geometry to come up with the optimum shape for each of the lower three reaches. The channel in the topmost reach (stations 0+00 to 23+00) was left unchanged for stability reasons. This phase of design depended greatly on the previous phases in that the channel geometry depends on the available slope of the channel, which in turn depends on the sinuosity of the channel and valley slope of each reach.

The final stage of design was to create a 1-D HEC-RAS hydraulic model of the reach. HEC-RAS calculates the water surface profile, mean depth, mean velocity, and mean shear stress. The HEC-RAS-predicted values were compared to those expected by designers to provide a check of the design parameters used.

Project designers developed a program of monitoring activities in an effort to evaluate the performance of the designed channel and to improve design principles for future projects. The hypotheses used as a basis for the monitoring program are described in the next section.

3.4 Project Monitoring Hypotheses

The physical monitoring plan for the project has gone through several revisions as new aspects of the project and monitoring are considered, but several basic hypotheses defined our approach in collecting data that will be used to analyze the success of the project. Those hypotheses follow:

1. The project reach will change over time from the baseline physical conditions;

2. Hydraulic models and assumptions used in the design were correct;

3. Minor movement in the channel bed and channel shape will occur during sub-bankfull flows (less than 1,700cfs) and significant movement (e.g. measurable bedload transport, measurable scour of the riffles, and measurable deposition on the point bars) will occur above bankfull flows.

4. Planform changes such as lateral channel migration are expected during flows of at least 5,000cfs (every five years on average).

The first hypothesis states that the project reach will change over time. This relates to the design assumption that the project will develop complexity over time. Monitoring parameters that will be used to test this hypothesis include surveys of the as-built channel profile and cross-sections every 100 feet, pebble counts at selected riffles and point bar apexes, and bulk samples at selected locations. The baseline data will be used to compare with later surveys, counts and samples to evaluate project performance. Specific objectives tested by this method include objectives D, F, and G.

The second hypothesis states that the hydraulic models and assumptions used in the design were correct. Specifically, this refers to the assumed "n" values of 0.035 to 0.04, that the bankfull flow begins to inundate the floodplain as modeled, and that the riffle depths and velocities are similar to the model results. The monitoring parameters used to test these model results and assumptions include surveys of water surface elevation and slope at various flows, installation and calibration of a flow gage on the project site, pebble counts performed on riffles to help determine bed roughness, and measured velocity profiles to allow comparisons between modeled and actual velocities. The resultant data will be used to evaluate the accuracy of the models and assumptions used in the design of the riffles, channel and floodplain. This evaluation will address objectives D, F, and G.

The third hypothesis is that the bed will not be significantly mobilized at sub-bankfull flows but will be significantly mobilized at flows at or just above 1,700cfs (bankfull). Monitoring actions related to this hypothesis include evaluating and resetting tracer gravel at selected sections, sediment transport sampling with a Helley-Smith sampler, cross-section and longitudinal profile surveys taken after 1,700cfs or greater or when tracer gravel has moved, installation and calibration of a flow gage on the site, and velocity profiles and pebble counts at selected cross-sections. In this report we will compare cross-section surveys with baseline data to evaluate whether scour and deposition occurred in response to flows of various magnitudes and present basic trends in changes to the surface grain sizes distribution. In future data analysis reports we hope to develop a sediment transport model based on monitoring results to predict transport rates and bed changes in the channel. This data will also be valuable in determining the quantity and quality of the gravel transported and will be used to determine the timing, quantity, and gradation of gravel augmentation material. These actions address objectives B, D, and F.

Our fourth hypothesis, that planform changes are expected during flows of 5,000cfs or every five years, is particularly applicable at the slope transitions, upper left-bank floodplain, and other floodplain features such as the simulated abandoned channels. Monitoring actions that are associated with this hypothesis include cross-section and profile surveys, data from pebble counts, bulk samples, tracer gravel experiments for use in a sediment transport model, flow and velocity measurements at selected cross-sections, and aerial photos being taken roughly every five years. These monitoring actions are planned to occur three times over a 15 year period. The surveys and other data will be used to compare with baseline data to assist in evaluation of planform changes. In the future, we hope to use the sediment transport model mentioned above to attempt to predict lateral channel migration and identify potential problems. These evaluations will address objectives B, D, E, and F.

3.5 Section 3 Figures

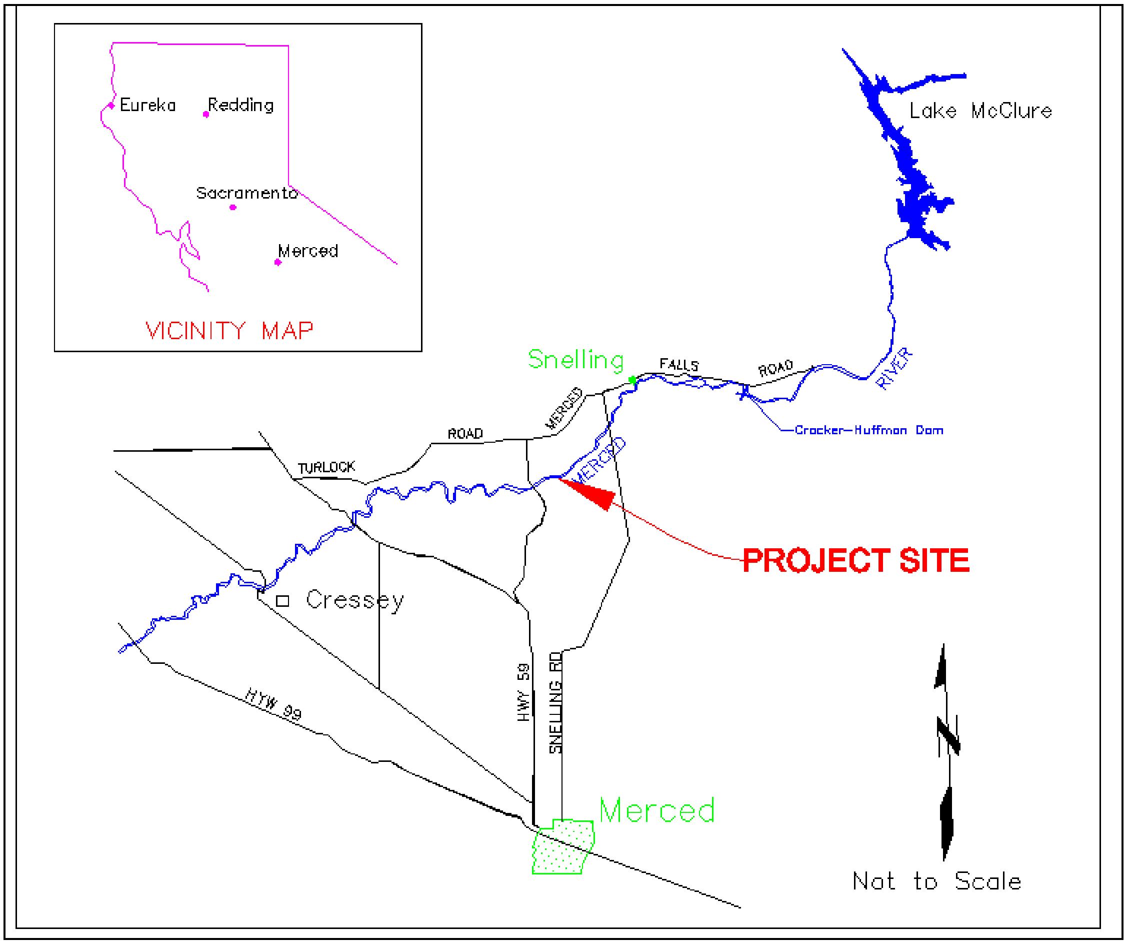


Figure 3.1.1. MRSHEP Phase III Location

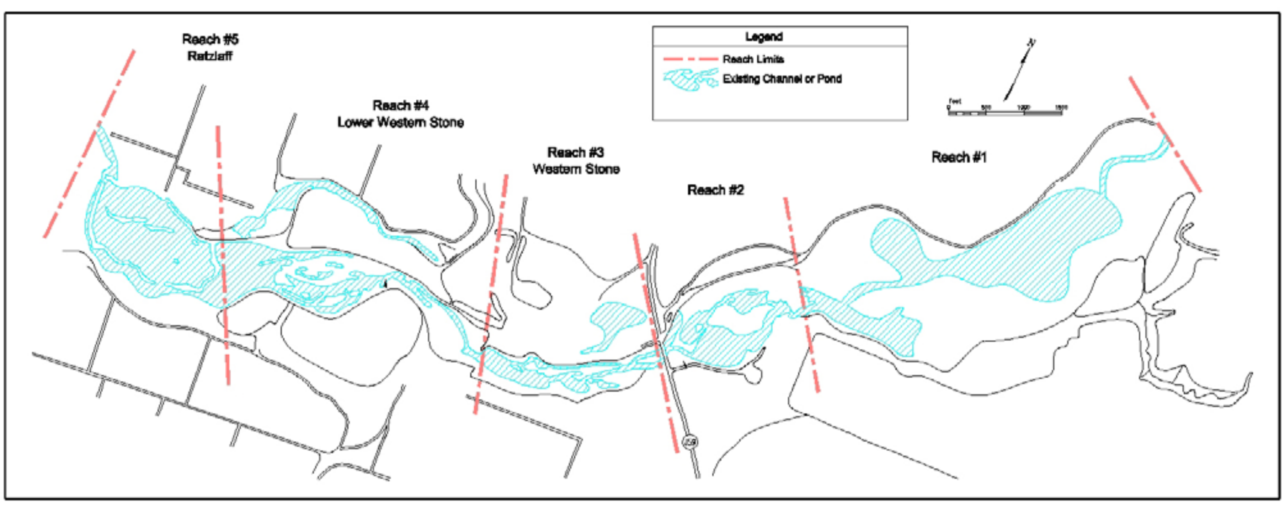


Figure 3.1.2. Merced River Salmon Habitat Enhancement Project

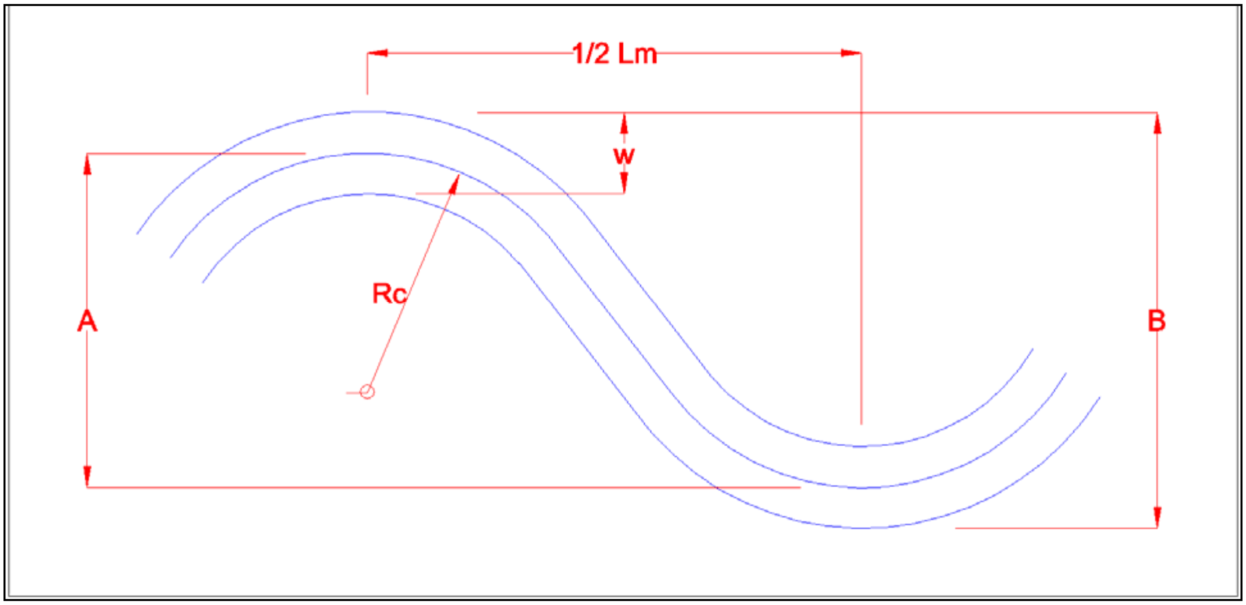


Figure 3.3.1. Meander Parameters (DWR, 2001)

4 CURRENT MONITORING PLAN AND ACTIVITIES OVERVIEW

Even before completion of the Robinson Reach project (see Figure 4.1.1) in February 2002, monitoring activities were already underway. Between late 2001 and late 2004, data was collected and analyzed through various activities including the installation of a flow gage, water surface surveys, velocity measurements, tracer gravel studies, pebble counts, bulk samples, transported sediment samples, cross-sectional surveys, and thalweg surveys. This section is meant to describe each of those activities and their implementation.

4.1 Background

Information about channel geometry, sediment characteristics, and hydraulic conditions can be used to evaluate the design and performance of the reach. These data are important in the attempt to understand the geomorphologic, hydraulic, and hydrologic processes taking place there. Nevertheless, finding the ideal locations for observation cross-sections is not a simple procedure. Unless the placement is primarily intended to be used to obtain data for a special area of interest, each monitoring section should be useful for several types of hydrologic and morphologic measurements and be representative of the reach.

As of late 2004, the geomorphologic and hydrologic processes acting on the newly constructed channel had not had adequate time to change the geometry of the reach significantly. That means that full equilibrium in the water/sediment system that characterizes channel stability has not completely evolved yet. As a result, special attention must be paid to the channel elements (such as riffle, pool, and transition reaches) during monitoring activities so that the affects of natural processes can be documented. The constructed reaches offer numerous opportunities for complex research and observations of the combinations of riffles, pools, and transitions, many of which will be discussed later in this report.

4.2 Monitoring Section Location Selection

The decision to design the reach using a single radius of curvature created an opportunity for studying the effects of different slopes and widths in the channel. The bends are seen as an important feature for study because they act to redirect flow as it leaves the sloped riffles, and they are expected to migrate through deposition on their inside banks and erosion of their outside banks. Another important constructed feature to mention is the transitions between the major channel elements, riffles and pools, where slopes, channel widths, and bed materials go through significant changes. Studying the water/sediment system's interaction in reaches where major changes occur is an important aspect of choosing monitoring cross-section locations.

The shape of the channel cross-section at any location is a function of the frequency, duration, and magnitude of water flow; the frequency, duration, quantity, and character of the sediment moving through the section; and the composition of the bed and bank materials. We believed from previous studies and observations that the midway points of the riffle, pool, and transition sections were best for hydraulic and hydrologic measurements because those are the locations where the extremes of hydraulic forces act on the riverbed. However, these points do not tell the whole story. Nearby channel portions both upstream and downstream should also be monitored because one observation point cannot adequately represent the full length of a given reach. We initially chose more sections than we believed we needed so that we could adjust our monitoring program later to focus on important areas when trends began to surface. Figure 4.2.1 illustrates the typical “riffle-pool” system concept that was used in the design of the Robinson Reach. The locations shown in the figure for deposition of material on the point bar and scour of the pool were predicted areas of interest for data collection. We expected that the outside banks of bends would be under erosion and inside banks under deposition. The locations of all monitoring cross-sections used in our monitoring study are shown in Figures 4.2.2 and 4.2.3.

4.3 Hydraulic and Hydrologic Monitoring

Monitoring activities presented in this paper are divided into two types: hydraulic/hydrologic and geomorphic. This section describes how we put together our hydraulic and hydrologic activities, which include the flow gage installation and monitoring and velocity profiles. It also describes why this data is important and what it will be used for.

4.3.1 Robinson Reach Flow Gage

A flow gage was necessary on the reach so that accurate flow data would be available to apply in our monitoring studies. We installed it on a selected cross-section near the upstream end of the Robinson Reach, which enabled us to record several types of measurements. Most significantly, it allows us to maintain a continuous record of water stage (height). When velocities and depths in the channel are measured, the stage record can be converted into water discharge. Other gages operated on the river include those closest to our project reach, the Snelling Gage and Cressey Gage. Those gages can be used in calibration and as a verification of proper operation of our gage.

4.3.1.1 Site Selection

Naturally formed riverbeds and banks are not usually ideal for gage placement because they change over time. Vegetation growth, bed and bank erosion, and bed sedimentation can take place, especially during the spring when maximum vegetation growth and water discharges occur. To utilize multiple water velocity and depth measurements made at various times, a rating curve is created that relates discharge to stage or depth. The stability of the relationship over time is primarily a function of the stability of the channel geometry that controls the water surface elevation at a given discharge. Changing riverbed elevations as a result of sediment movement, variations in vegetation growth, disturbance by man, and channel pattern may alter the gage characteristics.

Obviously, the best measurement accuracy would be attained at a weir-shaped section with a completely stable channel bottom and free from backwater influences from downstream. Unfortunately, that is not practical in wide rivers with rapidly changing discharges. A naturally formed channel section in the upstream portion of the project reach was selected. The guidelines we followed for site selection are outlined below:

1. The gage should be installed on the riverbank with the goal of recording depth at the chosen location. The maximum range of water levels and their locations should initially be visually estimated.

2. The main goal for the installed gage is to accurately measure water level changes corresponding to river discharge. Therefore, unstable riverbeds and riverbanks and vegetation indicate unsuitability for location of a gage because they can complicate

measurement processes. Because of that, we did not believe it to be prudent to set up a recording gage within the reconstructed channel.

3. In general, straight sections of channel with little turbulence are more desirable for measuring water depths, velocities, and water discharges than bends or pool sections.

4. Correct measurements from a gage require a uniform flow regime for some distance upstream and downstream. The desirable type of velocity profile distribution across and along the reach is smooth without any obstacles or debris.

5. It is preferable that the channel and riverbank of the cross-section be cleared of any debris or obstacles before gage installation, and that they remain maintained afterwards.

6. The best location for the gage is in a section of channel with relatively high banks, where higher flow events would be contained within the main channel.

7. It is important to select a location that has little or no backwater effects from downstream features.

4.3.1.2 Installation

Below is a brief description of the Robinson gage installation process. A diagram of the installed gage is shown in Figure 4.3.1, and the cross-section profile is shown in Figure 4.3.3. In our case, establishing the gage took one day for measurements, a second day for purchasing materials and assembling the apparatus, and two hours for installation.

1. Taking care to minimize damage to vegetation and riverbank soil and gravel, we placed a protective perforated pipe (last 2 feet perforated with ¼” holes) in the channel bottom and covered it with a layer of previously removed gravel. The gage sensor was installed inside of the perforated pipe.

2. One end of the pipe was covered with a cap with a small hole drilled in its center. This hole allowed a monofilament fishing line to be tied to the pressure transducer. This facilitated the removal and replacement of the transducer for maintenance and repair.

3. Rigid plastic pipe and elbows were used to extend the pipe up the riverbank, conforming to the shape of the bank, to the access point at the top. They were chosen such that the transducer would fit through them for easy maintenance. The pipe installed on the bank was buried approximately 3 inches beneath the surface.

4. To stabilize the pipe, three anchors were installed in the channel bottom adjacent to the pipe. They were two-foot long steel stakes about ½ inch in diameter, driven into the channel bed and bend around the pipe. The pipe was then tied to the steel stakes using stainless steel wire.

4.3.1.3 Calibration

After installation was completed, the sensor was calibrated with water depth measurements at the sensor location. To assist with comparison with the Snelling Gage, the Robinson gage was set to record at the same 15 minute interval as the Snelling Gage records.

We measured various water discharges during two high flow events to create a curve to calibrate the gage. The first point on the curve was zero discharge under zero water pressure or water depth. The other points were plotted as results of measurements at the various flows. The resulting curve (R^2=0.998) is shown in Figure 4.3.2.

Discharge is calculated based on recorded water depths with the equation:

$$Q = 10.345\ d^{3.696}$$

Where “Q” is total discharge and “d” is recorded stage.

4.3.2 Velocity Profiles

Velocity information for the monitored reach is crucial. It helps investigators understand the dynamics occurring in the channel, which in turn leads to a better understanding of and application to the geomorphic changes in the reach. We based much of our monitoring work on the velocity data we gathered, and some of the background for that effort is presented in this section.

4.3.2.1 Theory

It is well established that shear stress, τ, can be expressed as

$$\tau = KdV/dY, \tag{4.1}$$

where “V” is velocity, “Y” is depth, and “K” is a coefficient of molecular viscosity in the case of viscous flow. When flow is turbulent, “K” becomes the coefficient of eddy viscosity. In turbulent flow, momentum is transferred from fast layers of water near the top of the river to the slower layers near the bottom via small eddies. The shear stress is proportional to the velocity gradient (the change in velocity over some vertical distance) times a coefficient that represents the turbulent eddy characteristics. Near the bottom of a river channel, water velocity approaches zero. However, as you rise through the water column the velocity increases, and the rate of increase, “dv/dy”, is governed by the way in which the channel shape, slope, and depth changes. Studies have shown that a dimensionless number could express the laminar or turbulent character of flow. It is known as the Reynolds number,

$$Re=VD/(\mu/\rho), \tag{4.2}$$

where “V” is water velocity, “D” is depth, and “μ/ρ” is the kinematic viscosity (viscosity divided by the density). Under relatively uniform conditions, water velocities decrease logarithmically as they approach the riverbed. However, the shape of the vertical velocity profile can vary significantly throughout the channel due to factors such as bed forms or cross-channel (secondary) circulation patterns.

4.3.2.2 Activities

Water discharge is the product of the cross-sectional area of the flowing fluid and mean velocity. Velocity is defined as a vector having both direction and magnitude. As mentioned above, the water velocity is dependent on several factors, among which are energy gradient (approximated by water surface slope), depth, roughness, and radius of the channel curvature. Though in daily engineering practice water velocity magnitude is estimated using empirical formulas, it should be recognized that each cross-section of a channel has unique complex interactions between the flowing water, riverbed shape, and its sediment. As a result, the sequence and quantity of measurements on a monitored reach depend on the goals and purpose of the monitoring activities. In our case, three water velocity measurements (at different heights) at each measuring point along the sections is enough to fully represent the velocity distribution. The average water velocity for each cross-section resulting from these measurements may be defined as:

$$V_{average}=1/36(17V_{0.2}+3V_{0.6}+16V_{0.8}), \tag{4.3}$$

where "$V_{0.2}$, $V_{0.6}$, $V_{0.8}$" are the velocities at 0.2, 0.6, and 0.8 of the total water depth. The US Geological Survey recommends measuring water discharge in a way that is adequate for the hydraulic situation at each cross-section, but advocates the three depth velocity measurements as preferable. At each position the total depth is recorded and the effective cross-sectional area is calculated. Each mean velocity multiplied by the area results in discharges for each sub-area. These discharges are then summed to get the total discharge.

Staff measured vertical velocity profiles at 25 monitoring cross-sections in riffle, pool, and transition reaches over the period of March to July, 2002. Most sections were measured two to four times at various flows. Methods used included using a standard cup-type current meter and graduated staff. Because of the logarithmic variation in water velocity with respect to depth, the point of average water velocity does not fall in the center of the column. The average velocity generally occurs at a depth of 0.6D, or 60% of the depth below the water surface. Current meter measurements taken at this point give us the mean for the vertical section. If the measurements are also taken at 0.2D and 0.8D, the average of those readings can also be used as a close approximation of the mean velocity. Depths were recorded every two feet, and velocity was measured at 4 to 10 verticals along the section depending on width. Typical velocity measurement durations at each depth were 45 seconds.

4.4 Geomorphic Monitoring

The channel's ability to pass appropriate sizes of sediment is a major requirement in channel restoration design. As a result, high-flow events with different water discharge intensities that occur after construction are very important for collecting experimental data that should be used to improve future restoration design.

Geomorphic monitoring activities include activities that track changes in the bed and banks and floodplain of the river. Activities described below include bulk sediment sampling, pebble counts, tracer gravel monitoring, cross-sectional surveys, and bedload transport measurements. Data from these activities will help us understand and develop models for the reach that describe the sediment transport process so that we may predict future changes as well as compare observed changes with what the expectations were for the reach when it was designed.

4.4.1 Channel Bed Characteristics

Channel bed characteristics refer to the quantifiable aspects of channel bed materials. There are various methods for measuring the characteristics, two of which are pebble counts and bulk samples.

4.4.1.1 Theory

Bulk samples are used to characterize the material size breakdown at a particular point of a channel bed, bank, or other feature. Typically bulk sample data are used to create curves that are compared with sample data gathered from other points in a channel or with data sampled at other times at the same point. Pebble counts are a less labor intensive method of obtaining a fairly comparable set of data and are typically used in lieu of bulk samples. However, one important difference to note between the two types of data is that bulk samples will tend to include surface and subsurface material, while pebble counts only characterize surface material.

4.4.1.2 Activities

4.4.1.2.1 Bulk Samples

Two types of material were used in construction: "graded" material and "select" material. "Select material" is the unprocessed material excavated elsewhere on the Robinson Ranch. Select material was used to construct the floodplain and the outside bank of each pool. The grain size distribution data can be found in the Merced River Salmon Habitat Enhancement Project Phase III –Robinson Reach Engineering Report Table 6 (DWR, 2001) (see MRSHEP Phase III – Robinson Reach Engineering Report Figure 27 for typical fill placement). To create the graded material, other onsite material was graded to minimize the amount of finer grains (< 8 mm) and larger cobbles (> 100 mm). Bulk samples were taken from the graded material stockpiles during construction. The graded material was subsequently used in the channel construction as riffle bed material, riffle banks, and point bar material on the insides of channel bends. Four samples were collected ranging from 111 to 424 pounds each for a total of 1,087 pounds of sampled gravel. The samples were collected in 5-gallon buckets at various times from the stockpiles and transported back to the lab. They were then sieved and weighed.

4.4.1.2.2 Pebble Counts

Wolman pebble counts (Wolman, 1954) have been performed on all monitoring cross-sections in the reach. Pebble counts involve sampling the gravel particles on the surface of the channel bed and measuring those particles. Enough particles should be sampled (typically 100 per section) so that a statistical analysis can be done that simulates a sieve analysis. There have been studies done to show how to relate pebble counts to bulk sample sieve analyses (Leopold, 1970), but typically pebble counts are used to show bed material changes over time by comparing their results to other pebble counts at the section. However, when using particle sizes in sediment transport and critical shear stress calculations, it may be necessary to use a conversion. Our goal for these measurements was to be able to record changes in the reach in time at different section types and different reach slopes so temporal and spatial trends could be analyzed.

Most monitoring sections were sampled in July 2002, August 2003, and September 2004, with a few of them only measured on the most recent date. Samplers followed a procedure of splitting measurements along most cross-sections located on channel bends so that the left, center, and right portions of each cross-section were separately recorded. Both the overall size distribution and the lateral variations between each point bar and pool are reported in the results section; however, some caution in interpreting the results is necessary since 100 grains were counted for each cross-section and the left, center, and right side of channels are represented by only approximately 1/3 of the total grains measured.

4.4.2 Bed Mobility

4.4.2.1 Theory

Any particle on the riverbed surface exerts a vertical force equal to its weight on the particles upon which it rests. To move a gravel particle, the drag forces exerted by the flow on the grain must overcome the resisting force due to the immersed weight of the particle. The force exerted can be visualized as a torque, or couple, exerted by the flowing water dragging over the exposed top of the particle, or as a direct force of the water impinging on the area exposed to the flow. In either case, the force exerted is usually thought of as a drag stress proportional to the exposed area of the particle. In our cases, which are usually fully turbulent, the minute turbulent eddies near the riverbed cause a fluctuation of the local flow velocity at any one point. This gives some statistical or random chance that a given particle will move rather than its neighboring particle. If we solve for the force required to roll a particle out of its pocket, we get the following equation:

$$\tau_c = \tau^*_c(p_s - p_w)gD \qquad (4.4)$$

where τ_c is the critical shear stress (N/m^2) required to mobilize a grain with a diameter D, τ^*_c is dimensionless critical shear stress (an empirically derived coefficient that typically ranges from 0.030 to 0.086 for natural gravel bed rivers [Buffington and Montgomery, 1997]), p_w is density of water (kg/m^3), ps is density of sediment (kg/m^3), and D is the b-axis dimension of the grain (m).

Basic sediment transport theory tells us that when the mean shear stress exerted on bed particles by the flow of water ($\tau = p_w gdS$; where S = slope; d = depth (m)) equals the critical shear stress required to move a grain of diameter D, that grain will move.

4.4.2.2 Activities

4.4.2.2.1 Helley-Smith Sampling

A six-inch Helley-Smith bedload sampler (Helley, 1971) was used on 6 monitoring sections to collect data regarding sediment transport in the reach. The sampler was used at each section by placing it on the channel bed for 6 minutes for all but two samples. It collects transported rocks and sand that move along the surface of the bed in an attached 0.25mm mesh collection bag. The sampler is lifted after a specified period of time and the sample is saved for later analysis. We sampled at sections 4, 6, 9, 12, 13, and 24. Sections 6, 9, and 12 (riffle sections) were sampled multiple times at different flows. The procedure involved using a cable strung across the channel at higher flows so that a boat could be held in place for each sample. The sampler was attached to the boat with a boom and lowered vertically into the flow. The cable was anchored to a truck on each bank. This method can only be used up to approximately bankfull flows on this reach.

4.4.2.2.2 Tracer gravel studies

Tracer gravel studies involve taking specified sizes of gravel and placing them in the channel in a way such that individual grains can be tracked for movement in response to water flows (Figure 4.4.1). This activity helps engineers to understand the forces affecting sediment particles in the channel and channel changes as a whole

Typically, tracer gravel experiments are performed so that observations of particle movement are recorded at various flows. These mobility percentages at each flow would then be used to produce a chart of discharge vs. percent moved for each size class. This type of interpretation of tracer gravel gives the scientist a better understanding of the flows at which the bed material is under incipient and total mobility, which in turn allows planners to refine future volume and size distributions of gravel augmentation in the reach. If observations are conducted at the right flows, information can also be obtained about the lateral distribution of shear in the sections.

Tracer gravel movements were recorded after the high flow events in 2002 and 2003. Three size classes of tracer gravel were placed across monitoring sections 4, 6, 9, and 19 before the 2002 high flow event. The gravel used represented the D_{84}, D_{50}, and D_{31} of the bed material placed in the channel during construction based on bulk samples (Table 4.4.1). The particles were placed across each section, with the D_{84} on the section line, D_{50} one foot downstream, and the D_{31} an additional foot downstream. Each of the particles was tapped into the bed with a boot so that they behaved as part of the bed as flows increased. Each group of tracer gravel was made up of 14 particles, so each cross-section had 42 rocks for a total of 168 for all four monitoring sections. All tracer gravel particles for each cross-section were painted with a unique color for identification (Table 4.4.1).

After the 2002 event, we recorded the distance traveled of each particle found. For the 2003 event, the same cross-sections were used with the same percentile sizes as the year before; however, pebble counts indicated that the size distribution had changed for each cross-section (Table 4.4.1). Although the best practice is to have multiple observations as mentioned above, due to time and funding constraints, as well as difficulty of recovery during high flows, staff measured final distances after the conclusion of high flow events and carefully sorted tracer gravel specimens into their previously determined groups.

	2002				2003			
Monitoring Section	D_{84} (mm)	D_{50} (mm)	D_{31} (mm)	Color	D_{84} (mm)	D_{50} (mm)	D_{31} mm)	Color
4 (32+65)	113	65	40	Purple	105	65	45	Purple
6 (41+90)	113	65	40	Pink	93	65	50	Pink
9 (51+90)	113	65	40	Orange	86	53	38	Orange
19 (85+35)	113	65	40	Yellow	107	73	60	Yellow

Table 4.4.1. Tracer Gravel particles used in experiments

4.4.3 Channel Geometry

4.4.3.1 Theory

The geometry of a river channel is created and changed by the forces acting on it. The forces primarily are due to water flowing through the channel (flows that do not exceed the banks) and over the banks and floodplain (overbank or flood flows). It is widely accepted that a naturally evolved and maintained river channel is primarily shaped by "bankfull" flows, or the flow that fills the banks of the stream. These flows work on the bed and banks of the channel to create the features. Each feature, such as a riffle or pool, has an identifiable cross-sectional shape. Overbank flows should occur much less frequently, but usually have the capacity to alter the channel on a planform scale. This means that not only is the channel cross-section shape affected, but the lateral location of the channel can change. These channel shape and location changes can be monitored and studied to provide information about how the channel is reacting to the flows it experiences.

4.4.3.2 Activities

4.4.3.2.1 Cross-sectional Surveys

One of the most important and most basic methods of monitoring changes in the channel bed is by periodically recording the cross-sectional profile of the channel. Most often this is done by marking the monitoring section with semi-permanent markers such as rebar pins on each bank so that the same section is measured each time. Usually, the profile is recorded by means of survey equipment such as a level, rod, and tape, or other survey equipment. If careful attention is paid to noting location of the permanent markers, comparisons can be made to show scour or deposition of the channel bed, and channel migration or shape change.

Water depth measurements made while measuring flow were used to calculate flow area and for estimating cross-sectional changes for the period of March to May 2002. Measurements were performed for twenty-five Robinson Reach monitoring cross-sections during that 2002 high flow event. Later surveys were performed for each cross-section in July 2002, August 2003, and May or September 2004. Those surveys were conducted through the use of either a level and rod or a total-station EDM theodolite. In both cases, we used a permanent control network established after construction of the project to tie in to project elevations.

4.4.3.2.2 Channel Thalweg Profiles

The channel thalweg represents the lowest point of the channel. It shows the maximum depths at each point along the channel and also shows flow obstructions that cause ponding of water upstream. Thalweg profile monitoring is a useful way to show change in the channel bed over the length of the reach. A complete thalweg profile of the reach was surveyed in August 2003 and May 2004.

4.4.3.2.3 Aerial Photographs

Photographs of the site in plan view are a useful tool for monitoring several features through comparison of photos taken over time. Any change in channel location or width is recognizable, as well as change in vegetation cover. Tools are being developed that will use aerial photography to determine underwater topography as well. Aerial photos have been collected or produced by DWR for pre-project, as well as post-project in 2002 and 2003. Some of these photos are shown in Figure 4.1.1.

4.5 Section 4 Figures

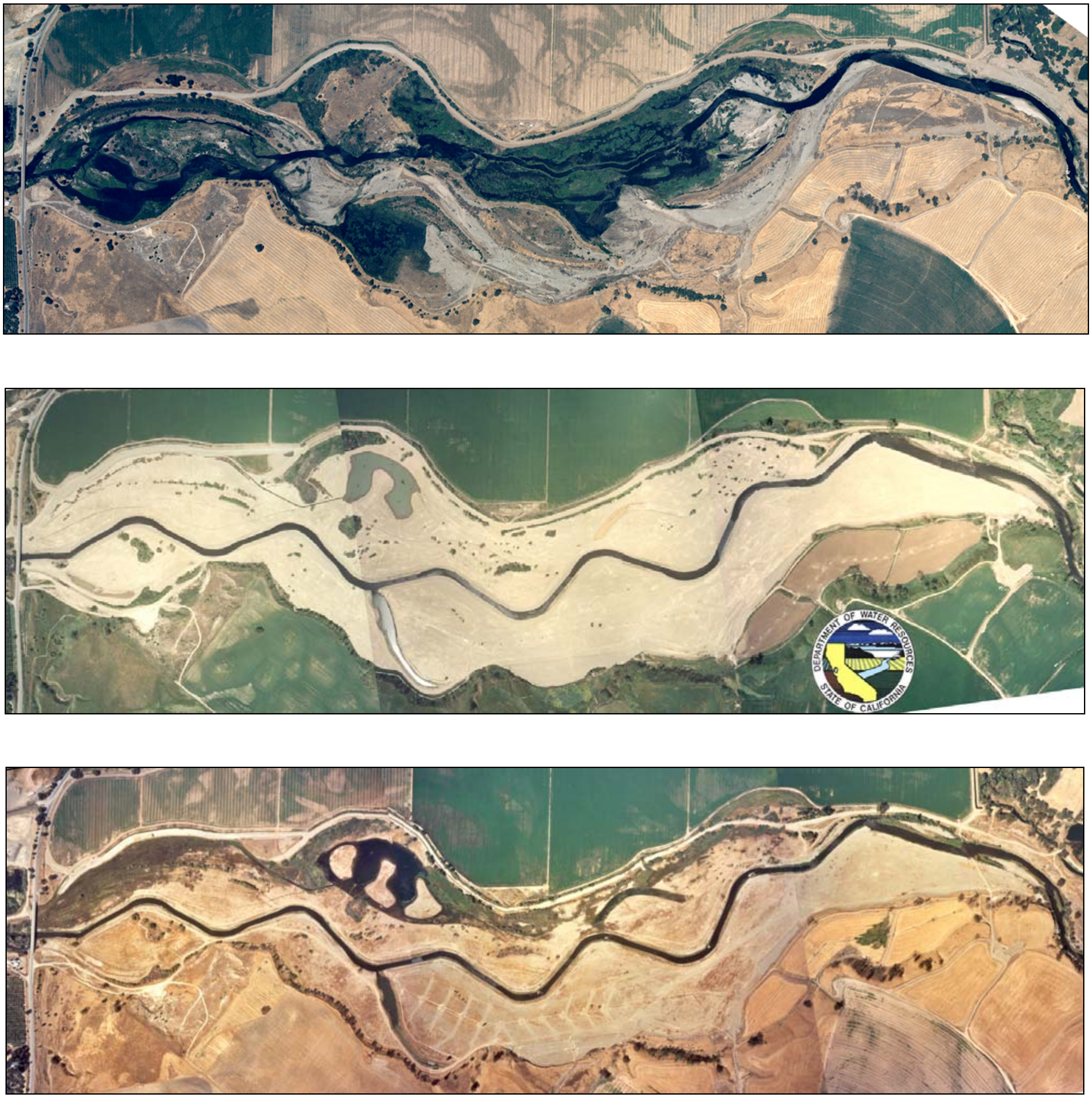


Figure 4.1.1. Project Reach Aerial Photos: pre-construction, 2001 (top); post-construction, April 2002 (middle) and September, 2003 (bottom)

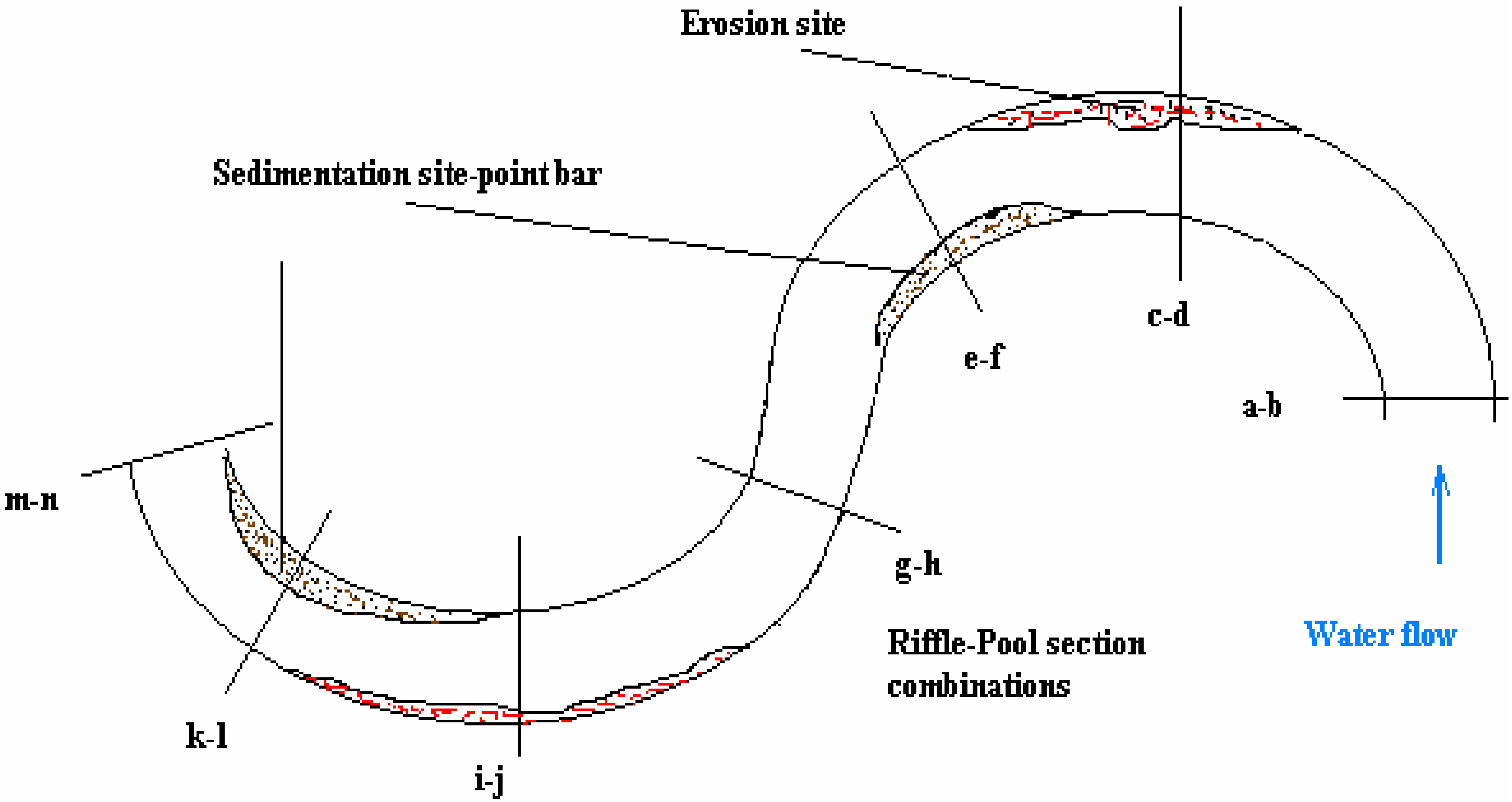


Figure 4.2.1. Simplified view of expected locations of processes and recommended cross-section locations for geomorphologic, hydraulic, and hydrologic measurements on the Robinson Project site

Figure 4.2.1

Figure 4.2.2. Monitoring Section Locations, Upstream Half

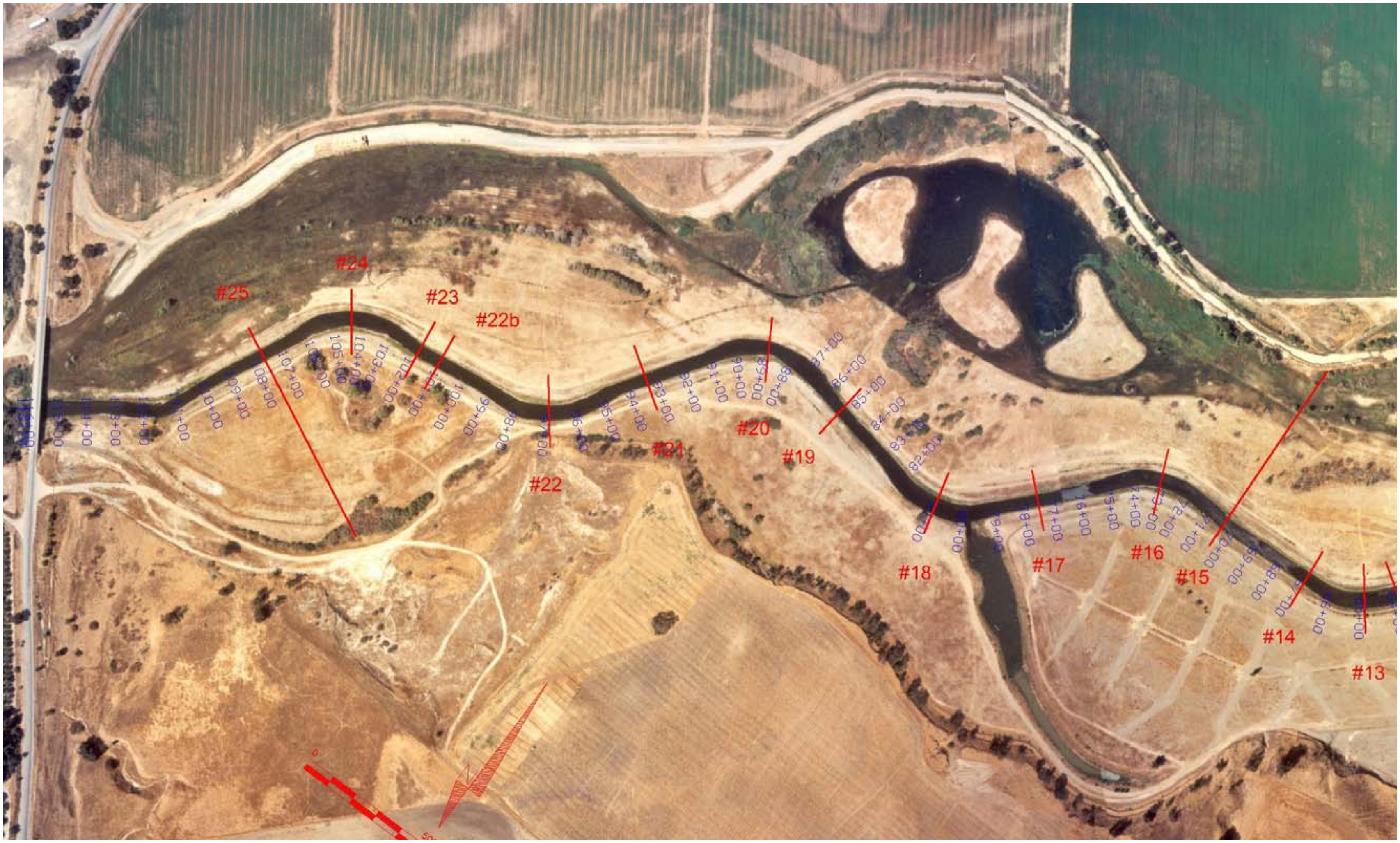


Figure 4.2.3. Monitoring Section Locations, Downstream Half

Figure 4.2.3

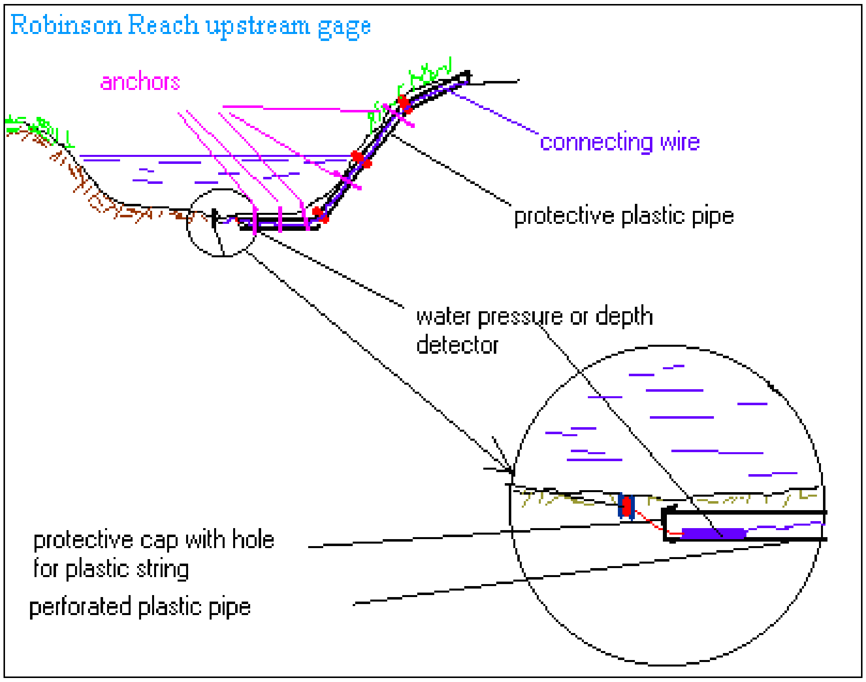


Figure 4.3.1. Gage installation detail

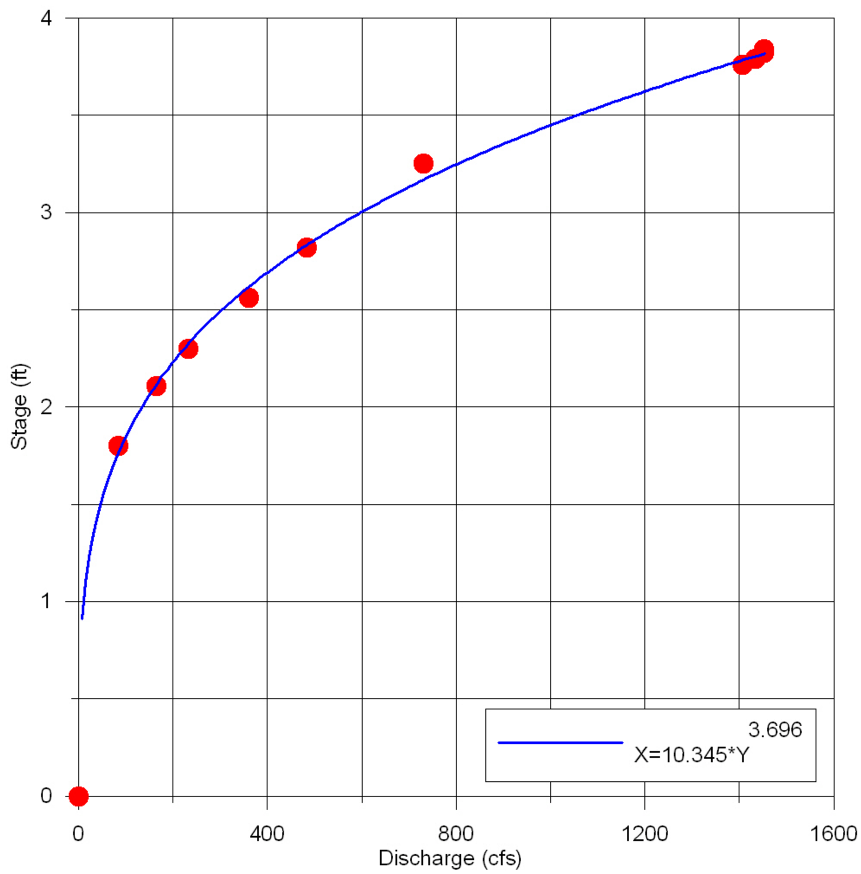


Figure 4.3.2. Robinson Gage Rating Curve, Fall 2002

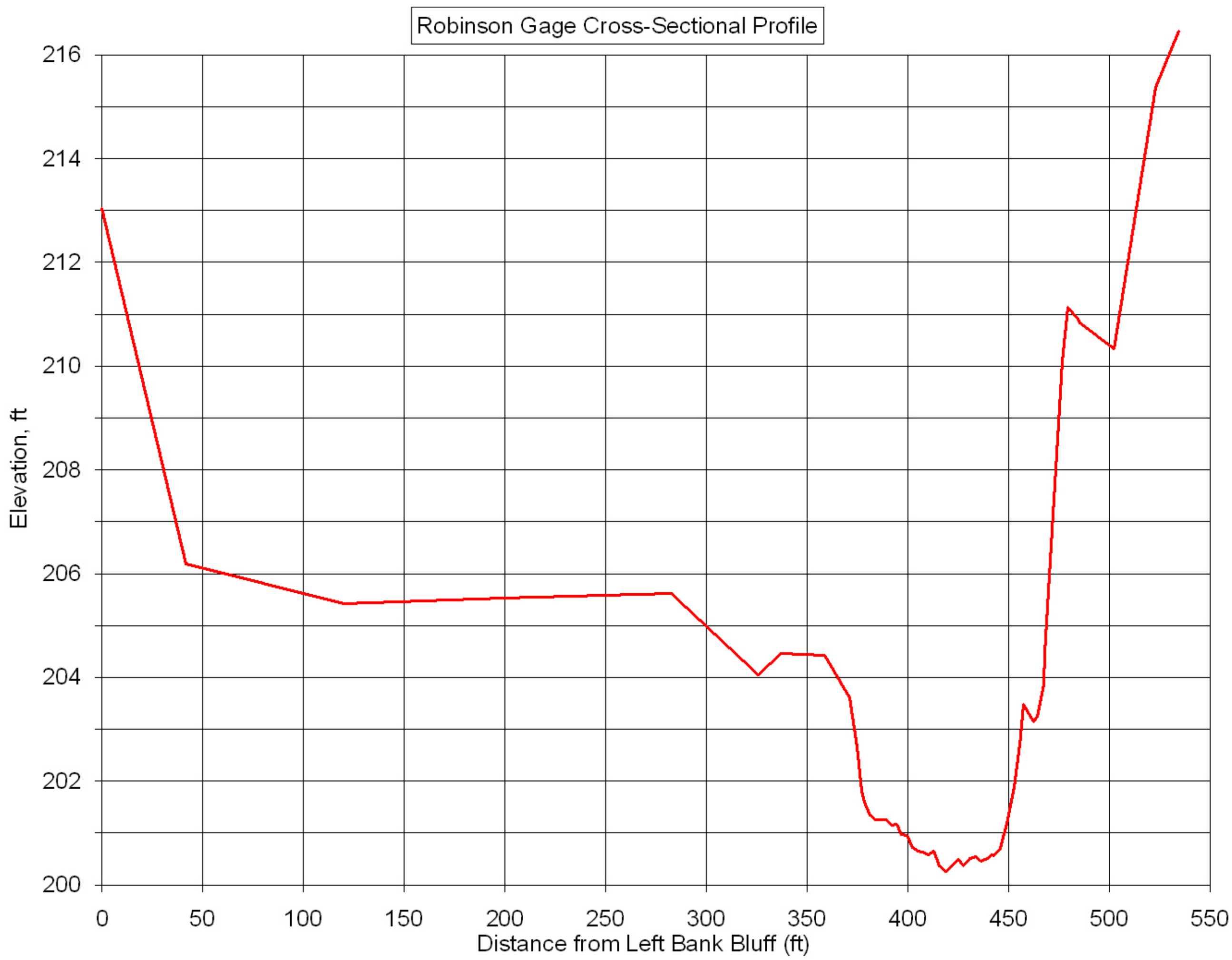


Figure 4.3.3. Robinson Gage Section Surveyed Profile

Figure 4.4.1. Photo of typical riffle section with installed tracer-gravel indicators

5 MONITORING DATA PRESENTATION

The activities described in Section 4 of this paper yielded results and information about the project. In this section, the data gathered is presented in various tables and figures. Because of the large number of tables and figures, they are found at the end of the section. Discussion of the data follows in Section 6.

5.1 Hydraulic and Hydrologic Data

Hydraulic and hydrologic data are presented in this subsection in the form of hydrographs, velocity profiles, and relationships developed through the activities described in Section 4.3.

5.1.1 Robinson Reach Flow Gage

Section 4.3.1 described the process we went through in putting in place a flow gage on the project site, why we needed it, how we selected a site for it, and the procedure we used for installation. It also detailed the calibration of the gage.

5.1.1.1 Results

Recorded water surface stage was converted to discharge using the equation presented in the calibration section. The entire hydrograph from October, 2002 to December, 2004 is shown in Figure 5.1.1, along with the Snelling Gage record from October, 2001 to December, 2004.

The calculations and estimates made for this gage cross-section are valuable if they are comparable with water discharge data collected at the Snelling Gage site. Differences between hydrographs at the two gages can occur due to the loss of water in the reach between the gages. Merced River water is used for irrigation, mining, and other domestic purposes, and losses may also occur to groundwater. On the other hand, if the distance between two sites is not great, comparisons can be made if diversion quantities are well known. It appears from the hydrographs in Figure 5.1.1 that there is a fairly consistent difference in flows between the two gages. A correlation plot of the data for both sites is shown in Figures 5.1.2 and 5.1.3. The data is for the mean daily flow at each gage, and is separated into several periods of record. The separation of time periods is based on seasonal differences, such as high and low flow releases, diversion season for irrigation, and the rainy season that contributes runoff between gages. Each season has a slightly different correlation between the Robinson and Snelling gages.

The correlation shows that at low flows (less than 400cfs), the flow at Snelling Gage is almost always higher than at Robinson Gage. The differential is anywhere from 0 to 100cfs, but seldom less than zero. Excluding records prior to March 31, 2003, there is a strong tendency for a Snelling discharge 75cfs higher than at Robinson. At higher flows (greater than 800cfs), Snelling seems to run less than 50cfs above Robinson at 800cfs, but converges to a 1 to 1 ratio as flows approach 2000cfs. This data will be helpful in estimating flows at the Robinson site in the absence of Robinson Gage data.

5.1.2 Water Surface Profiles

Data collected during the flow measurements and cross-sectional surveys was used to create the water surface profile at various flows through the reach. Staff also marked high water during the May, 2004 high flows. These data were plotted with the thalweg profile of the reach (Figure 5.1.4).

Enough data is available for most of the profiles to show surface slope variations between riffle and pool sections. Steeper drops are seen in the riffle sections than in pools, which is consistent with the hydraulic response expected by designers. Depths also appear to meet design expectations, with spawning flows (200-250cfs) maintaining 1.5 to 2 feet of depth in the riffle sections.

5.1.3 Velocity Profiles

The velocity profiles were generally logarithmic in shape (see Figures 5.1.8 and 5.1.12 for typical pool and riffle profiles). This was expected due to the relatively uniform shape of the channel. The small longitudinal slopes (0.0010 to 0.0015) of pool sections result in lower mean velocity values, while the higher mean velocity values of the transition sections result from slopes of 0.0014 to 0.0030. Riffle sections have the highest mean velocities due to slopes ranging from 0.0025 to 0.0040.

The mean velocities in the reaches during the higher flow events varied from 0.001 ft/sec to 6.5 ft/sec. There are, of course, many local situations where channel geometry causes velocities to attain greater values. Using the vertical velocity profiles measured at each cross-section we compiled isovel maps (Figures 5.1.5 to 5.1.28). Flows shown for each are the mean daily flows recorded at Snelling Gage.

5.2 Geomorphic Data

As described in Section 4.4, we undertook several monitoring actions to track geomorphic changes in the reach. Data collected includes sediment sampling, pebble counts, tracer gravel studies, and cross-sectional and profile surveys.

5.2.1 Channel Bed Characteristics

5.2.1.1 Bulk Samples

Bulk samples of graded material collected before material placement in the channel during construction were sieved, and the results are presented in Figure 5.2.1. The figure presents data for each of the four sampled stockpiles as size distribution curves, along with the curve for the total of all samples. The resulting weighted average (samples from larger stockpiles given more weight than smaller ones) D_{50} was about 57mm, while the D_{84} was about 86mm.

5.2.1.2 Pebble Counts

The pebble counts described in Section 4.4.1 were completed and the results for each monitoring section charted as particle size distributions (Figures 5.2.2 to 5.2.32). The D_{50} and D_{84} for riffle sections are reported in Table 5.2.1. In looking at both the graphs of the particle size distributions and the representative D_{50} and D_{84} values for each of the distributions, we can look for trends in bed material changes. When directly compared to the bulk sample results (Section 5.2.1.1), it appears the surface of the newly constructed channel bed coarsened somewhat in response to sub-bankfull flows during the fall of 2001 and spring of 2002; however, since 2002, the surface has slightly, yet noticeably, fined in most cases (Table 5.2.1, Figure 5.2.33).

section	2002		2003		2004	
	D_{50} (mm)	D_{84} (mm)	D_{50} (mm)	D_{84} (mm)	D_{50} (mm)	D_{84} (mm)
1	87	125	68	105	58	110
2b					70	125
4b					68	113
6	65	93	61	102	50	96
9	53	86	56	92	63	100
12	62	92	49	80	53	88
15	73	113	58	100	66	104
17	70	111	40	76	54	89
19	73	107	53	84	59	97
21	74	106	51	84	57	90
23	49	80	46	79	45	73
25	67	94	50	83	55	85

Table 5.2.1. Riffle Section Pebble Count Results, D_{50} and D_{84}

In the pool sections, the insides of bends are consistently finer than those of the outside of bends (Table 5.2.2); however, this data should be interpreted with some caution at a single point bar-pool pair due to the sample sizes. The overall averages for all pool sections show a 2002 D_{50} of 34mm for the inside and 72mm for the outside. Put another way, the D_{50} of bed material on the outside is about 2.1 times the size of that of the inside material. There is a similar pattern for the D_{84} values in 2002. In 2004, the D_{50} and D_{84} differences between outside and inside are similarly a factor of about 1.5. It is interesting to note, however, that sizes for the inside material increased slightly from 2002 to 2004, while sizes of outside material decreased over the same period.

Pool Section Pebble Count Results						
	inside		outside		outside:inside ratio	
Year	D_{50}(mm)	D_{84}(mm)	D_{50}(mm)	D_{84}(mm)	D_{50}	D_{84}
2002	34	67	72	125	2.1:1	1.9:1
2004	41	75	62	111	1.5:1	1.5:1

Table 5.2.2. Pool Section Pebble Count Result Averages

Another trend we see has to do with the gravel sizes in riffles by reach. The constructed project was broken up into four design reaches, with the upstream-most reach left at its existing channel configuration and each of the other three reaches with different design slopes for the new channel (DWR, 2001). 2004 pebble count results appear to show that the steeper riffles are maintaining coarser beds than those with shallower slopes (Table 5.2.3).

2004 Riffle Section Pebble Count Results Averaged by Reach			
Design Reach (Design Station)	Design Riffle Slope	D_{50}(mm)	D_{84}(mm)
2 (23+00 to 35+00)	0.0040	69	119
3 (35+00 to 54+00)	0.0035	57	98
4 (54+00 to 116+00)	0.0025	56	89

Table 5.2.3. 2004 Riffle Section Pebble Count Results Averaged by Reach

5.2.2 Bed Mobility

5.2.2.1 Hydraulic Model

We developed a new HEC-RAS model, a one-dimensional channel hydraulics model that simulates flow through a channel, based on 2004 channel geometry to support the analysis of sediment transport calculations. Information from profile surveys and high water mark surveys were used in the model to develop several profiles (flow events). We made assumptions for bed roughness, slopes, and starting water surface elevations. All 32 monitoring cross-sections were used in the model, defined by the 2004 survey geometry. Several intermediate sections had to be interpolated to define the extents of riffles so that the model could be calibrated properly. Those sections were based on the surveyed riffle sections, but adjusted by the channel slope and the surveyed 2004 thalweg elevation for those points in the channel.

The model was calibrated through the use of observed water surface elevations at 71, 225, 400, and 1,605cfs. It was then used to simulate various flows between 100cfs and 1,800cfs. The channel shear values vs. flow generated from the model at each section are shown in Figures 5.2.34a and 5.2.34b. The model output was also used to create a shear vs. station graph, which is presented in Figure 5.2.35.

5.2.2.2 Helley-Smith Samples

Six monitoring cross-sections were sampled using a Helley-Smith bedload transport sampler during various flows in 2002 (Figure 5.2.36). Three of the cross-sections, numbers 4, 13, and 24, are in pool or transition portions of the channel. The other three sections, numbers 6, 9, and 12, are in riffle portions. The bedload samples collected at the riffle sections were used to analyze bedload transport in that part of the reach because we sampled at multiple flows at those sections.

The samples were taken with a Helley-Smith style sampler with a six-inch by six-inch orifice. The dates and corresponding flows for each sampled section are shown in Table 5.2.4 below. Gradation curves of the samples are shown in Figures 5.2.37 to 5.2.40.

Bedload Transport Analysis Data Helley-Smith Samples		
Date	Sections Sampled	Avg Measured Flow (cfs)
April 16, 2002	9	354
April 23, 2002	6, 9, 12	444
April 25, 2002	24	403
May 2, 2002	4, 6, 9	1,312
May 8, 2002	6, 9, 12, 13	923

Table 5.2.4. Helley-Smith Sampling Dates and Locations

Bedload discharge is determined from the weight of sediment trapped per unit time in the sampler taken at several locations on a stream bed. Measurements should be performed at various discharges to enable the creation of a rating curve to show the relationship between water discharge and sediment transport (Starosolszky, 1987). At each riffle cross-section (sections 6, 9, and 12), we took measurements at various sub-bankfull flows; however, time did not permit us to take multiple samples at each flow in most cases. This resulted in a relatively rough representation of sediment transport at the sections. Table 5.2.5 summarizes the data obtained from all samples and appears to show that significant movement of coarse material occurred on the riffles in 2002 during sub-bankfull flows. Because the largest particle takes up a significant percent of the total sample weight, any reported D_{50} should be interpreted with much caution. Typically, the largest particle in a sample should not occupy more than 1% of the total sample by weight for particles less than 32 mm (Church et. al, 1987; Bunte and Abt, 2001), although a more relaxed criterion of 5% is sometimes used (Mosely and Tindale, 1985). The bedload samples also appear to show that the pools are transporting fine gravels during flows significantly less than bankfull.

XS	Description	River Station (ft)	Sample #	Flow (cfs)	Duration of Sample (min)	Sample Weight (lb)	Max Particle Size (mm)	(Max particle Weight)/ (Total Sample)*	D50 (mm) **	Bedload Rate (lb/min/ft)	Bedload Rate (kg/s/m)	% Bedload < 2mm***	%Bedload < 8 mm***	Approx. Location
6	riffle	4190		444	6	2.06	72	29%	38	0.69	0.017	0.00%	0.00%	Center, 30' from LB
6	riffle	4190		923	6	1.16	70	39%	38	0.39	0.010	0.00%	0.00%	Center, 37.5' from LB
6	riffle	4190	1	1312	0.17	0.33	29	23%	18	3.92	0.097	3.06%	8.82%	Center, 43' from LB
6	riffle	4190	2	1312	6	1.71	66	35%	33	0.57	0.014	2.80%	6.13%	8' from LB
6	riffle	4190	combined	1312		2.04	66	30%						
9	riffle	5190		354	6	0.28	35	46%	25	0.09	0.002	1.90%	9.28%	Center, 27' from LB
9	riffle	5190		444	6	0.85	46	35%	30	0.28	0.007	0.00%	1.30%	Center, 28' from LB
9	riffle	5190		923	6	0.34	61	78%	50	0.11	0.003	3.22%	5.85%	Center, 37.5' from LB
9	riffle	5190		1312	3	1.59	44	17%	30	1.06	0.026	0.69%	1.26%	7' from LB
12	riffle	6070		444	6	0.65	35	20%	22	0.22	0.005	0.74%	2.70%	Center, 31' from LB
12	riffle	6070	1	923	6	7.88	85	24%	38	2.63	0.065	2.18%	5.29%	25' from LB
12	riffle	6070	2	923	6	5.50	81	30%	26	1.83	0.046	3.63%	9.47%	50' from LB
12	riffle	6070	combined	923		13.38	85	14%	30					
4	transition	3265		1312	6	1.44	66	61%	64	0.48	0.012	3.25%	3.61%	Center
13	pool	6465		923	6	0.53	21	5%	8	0.18	0.004	27%	56%	15' from LB
24	pool	10420		403	6	0.39	23	10%	6.2	0.39	0.010	67.55%	77.50%	15' from RB

* The largest particle in a sample should occupy less than 1% of the total sample for Dmax particles less than 32 mm (Church et. al, 1987; Bunte and Abt, 2001). A more relaxed criterion of 5% is sometimes unavoidable (Mosley and Tindale, 1985).

*** Original grain size distribution placed in channel had between 0-1.9% grains < 6.35 mm and between 0-2.3% < 8 mm by weight.

Table 5.2.5. Helley-Smith Data Summary Table

We devised a simplistic method to estimate the bedload transport based on the riffle section measurements. It involved taking a simple average of the transport rate over the width of the sampled section. Transport was assumed to vary linearly between sampled points and the channel banks, with zero transport assumed at each bank based on visual observation. With only one or two samples at each flow, the quality of the samples is vital in determining the overall transport rate with this method. Graphical representations of the computations are shown in Figure 5.2.41.

The total transport calculated from each sample was plotted by section to develop a Discharge vs. Transport relationship, as shown in Figure 5.2.42. Although results comprised only a few data points, there is an apparent trend in the average transport rates from 1.8tons/day at 354cfs to 76tons/day at 1,312cfs.

5.2.2.3 Tracer gravel studies

Recovery of tracer gravel is shown graphically in Figures 5.2.43 to 5.2.50. As described in Section 4.4.2.2, 14 particles of each size were placed on each of the four sections prior to spring flows in 2002 and 2003, with one third of the particles placed in each third of the section (left, center, right). According to Figure 5.1.1, flows peaked at about 1,400cfs in late spring 2002 and 1,550cfs in late spring 2003. Total recovery numbers are shown in Table 5.2.6. The gravel sizes used for the tracers are reported in Table 4.4.1. A comparison of the total number of tracers that did not move at all in 2002 compared to 2003 indicates that the bed was much more mobile in 2002 than in 2003, a trend that is consistent with the Helley-Smith and survey data.

2002 Tracer Gravel Recovery												
	Placed			Did Not Move			Recovered Moved			Unrecovered		
Section	D31	D50	D84	D31	D50	D84	D31	D50	D84	D31	D50	D84
4	14	14	14	0	0	0	4	3	8	10	11	6
6	14	14	14	0	0	0	0	0	2	14	14	12
9	14	14	14	0	0	0	1	4	9	13	10	5
19	14	14	14	0	0	0	2	9	13	12	5	1

2003 Tracer Gravel Recovery												
	Placed			Did Not Move			Recovered Moved			Unrecovered		
Section	D31	D50	D84	D31	D50	D84	D31	D50	D84	D31	D50	D84
4	14	14	14	3	5	10	2	0	1	9	9	3
6	14	14	14	0	0	1	0	1	1	14	13	12
9	14	14	14	1	1	1	2	1	1	11	12	12
19	14	14	14	2	2	5	3	6	8	9	6	1

Table 5.2.6. Tracer Gravel Recovery Total

5.2.3 Channel Geometry

5.2.3.1 Cross-sectional Surveys

Channel cross-section profiles are presented in Figures 5.2.51 to 5.2.82. They represent all of the monitoring sections and show both flow measurement depths and surveys done with survey equipment. They also show the design profile or elevation for each section. Upstream of cross-section 17, the mean riffle bed elevation measurably scoured in 2002 in response to sub-bankfull flows; however, only minor bed elevations adjustments occurred in the same riffles in 2003 to 2004 in response to peak flows of equal or greater magnitude (see Figure 5.1.1). Downstream of cross-section 17, the bed elevation has locally adjusted, but the mean bed elevation has not significantly changed since construction. Cross-sections at the head of each pool from stations 31+10 (XS 3) to 63+70 (XS 12b) show that deposition of point bars has occurred at the inside of those channel bends since construction. Cross-section 3 (the only cross-section through a point bar surveyed in both 2003 and 2004) shows that measurable deposition occurred each year. Downstream of cross-section 12b, no point bar formation has been observed and thus no additional monitoring cross-sections have been established.

5.2.3.2 Channel Area Changes

One way to measure change in the cross-sectional characteristics of the channel is to use the surveys to calculate total change in area. In this case, we totaled conveyance area of the channel, or the cross-sectional area open to water flow below the top of bank elevation, for each survey. Figures 5.2.83 to 5.2.89 show these values as a percent change from the original March, 2002 survey. We did not have survey data from the time immediately after channel construction, and we did not use the design geometry for this comparison. We made the decision not to use the design geometry because, although significant changes may have taken place before March 2002, the channel as constructed would not have reliably followed design dimensions to the precision necessary for this comparison.

The changes are plotted on a time scale along with the Snelling Gage mean daily flow hydrograph. Sections chosen for the plots included riffle or transition sections, most of which are located in the upper reaches of the project where slopes are steeper and sediment transport is expected to be higher; however, some sections from the lower gradient downstream reach are also shown. The results show that nearly all of the riffle sections increased in conveyance area, which translates to a loss of bed or bank material. The only exception was section #12, just downstream of a gradient change, which showed almost no change in total area.

Another way to show these changes is to plot total conveyance area change in square feet vs. location in the reach. Figure 5.2.90 shows this depiction for the period of March 2002 to July 2002. The figure shows positive changes in conveyance area for the period at most sections of the channel, with the exception of sections immediately downstream of channel slope changes. Figure 5.2.91 shows changes for the period of July 2002 to May 2004. This figure illustrates that far less change occurred in the two years since the first flow events after construction. The final figure, Figure 5.2.92, illustrates the change over the entire monitoring period.

5.2.3.3 Channel Thalweg Profiles

A complete thalweg profile of the reach was surveyed in August 2003 and May 2004. They are shown in Figure 5.2.93 along with previously surveyed thalweg points and the design thalweg. Although it appears from the figure that significant scour occurred in the riffles between construction and August 2003, this is exaggerated by the fact that the channel was designed with a flat bed. As the channel increases in complexity, the thalweg will tend to drop while other portions of the section may rise. However, the figure does show an overall tendency of degradation of the channel bed in 2002, which is consistent with the data presented in previous sections.

5.3 Section 5 Figures

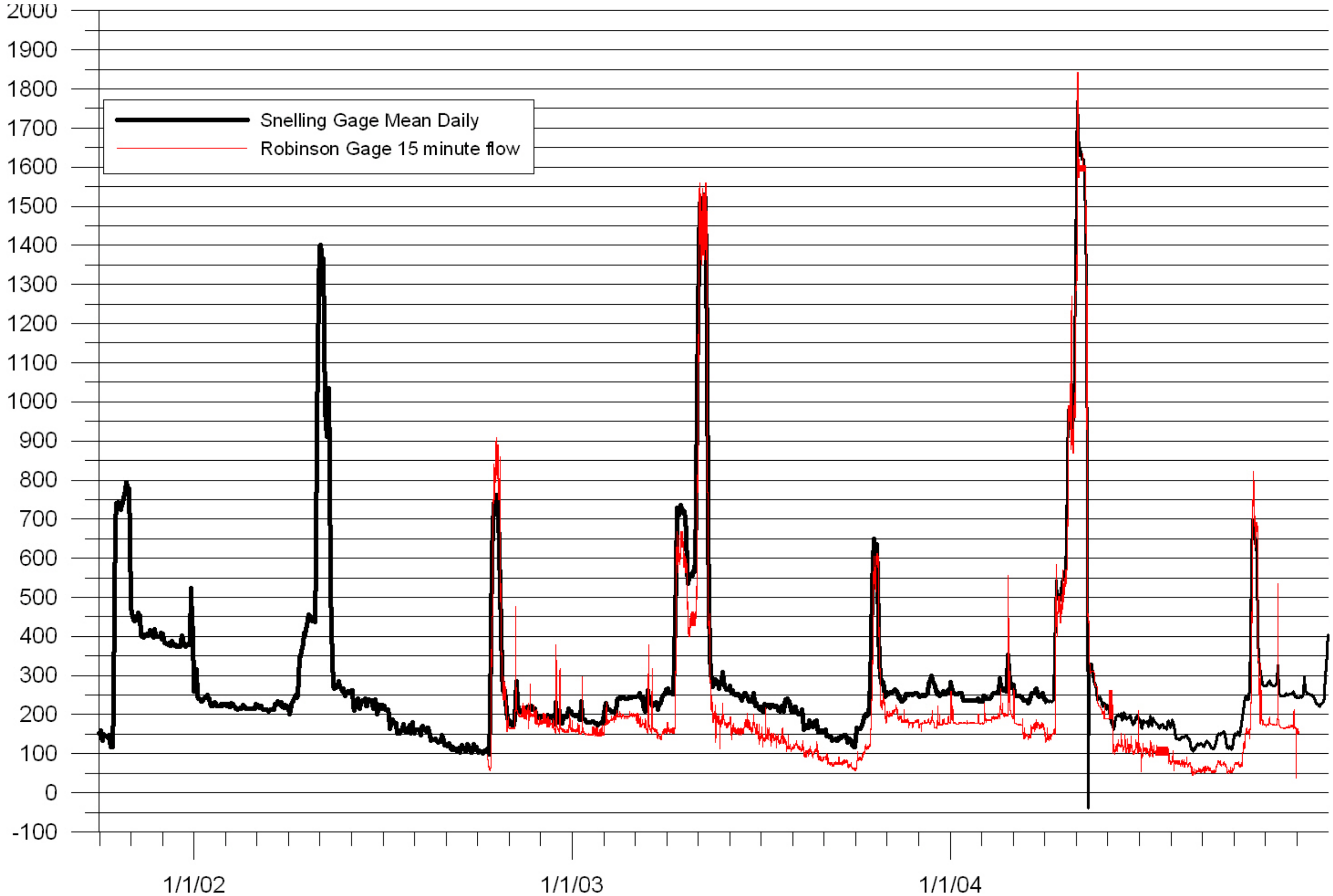
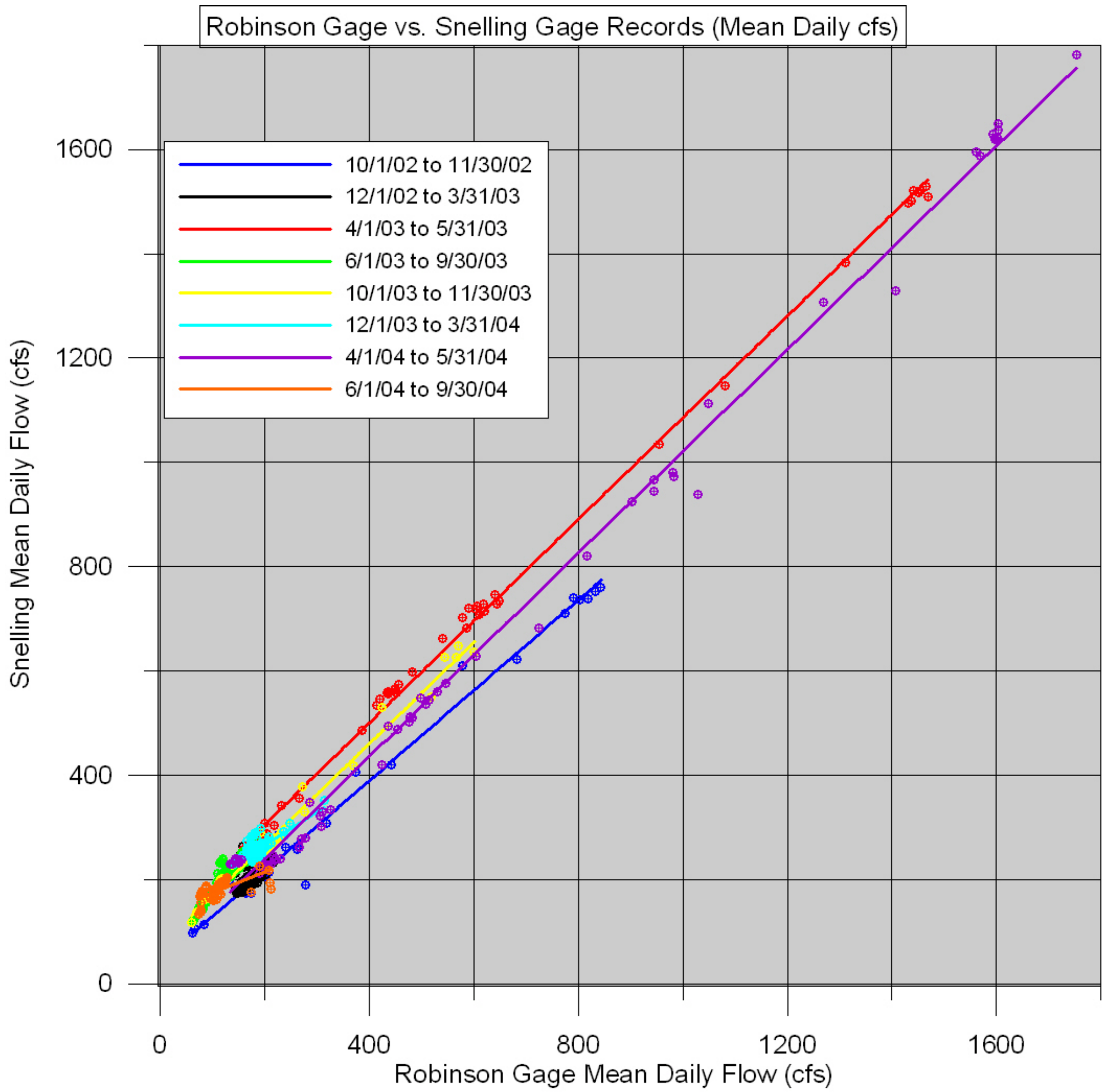


Figure 5.1.1. Snelling Gage Mean Daily Flows (CDEC) and Robinson Gage instantaneous flow record.

Figure 5.1.1



10/1/02-11/30/02
Equation Y = 0.8662811154 * X + 42.43472382
Number of data points used = 51
Average X = 288.201
Average Y = 292.098
Residual sum of squares = 22381.1
Regression sum of squares = 1.80143E+006
Coef of determination, R-squared = 0.987728
Residual mean square, sigma-hat-sq'd = 456.758

12/1/02-3/31/03
Equation Y = 0.7791150611 * X + 77.27832247
Number of data points used = 121
Average X = 171.93
Average Y = 211.231
Residual sum of squares = 48670
Regression sum of squares = 25723.5
Coef of determination, R-squared = 0.345777
Residual mean square, sigma-hat-sq'd = 408.991

4/1/03-5/31/03
Equation Y = 0.9751006994 * X + 109.8718609
Number of data points used = 61
Average X = 503.501
Average Y = 600.836
Residual sum of squares = 14247.2
Regression sum of squares = 1.00344E+007
Coef of determination, R-squared = 0.998582
Residual mean square, sigma-hat-sq'd = 241.477

6/1/03-9/30/03
Equation Y = 1.170844455 * X + 57.18741915
Number of data points used = 122
Average X = 119.944
Average Y = 197.623
Residual sum of squares = 17592.3
Regression sum of squares = 198128
Coef of determination, R-squared = 0.918449
Residual mean square, sigma-hat-sq'd = 146.603

10/1/03-11/30/03
Equation Y = 0.9692196514 * X + 72.23167745
Number of data points used = 61
Average X = 210.256
Average Y = 276.016
Residual sum of squares = 14498.9
Regression sum of squares = 853512
Coef of determination, R-squared = 0.983296
Residual mean square, sigma-hat-sq'd = 245.744

12/1/03-3/31/04
Equation Y = 0.63672575 * X + 138.4062035
Number of data points used = 122
Average X = 181.415
Average Y = 253.918
Residual sum of squares = 17038.2
Regression sum of squares = 20067
Coef of determination, R-squared = 0.540815
Residual mean square, sigma-hat-sq'd = 141.985

4/1/04-5/31/04
Equation Y = 0.9762365482 * X + 44.12668746
Number of data points used = 61
Average X = 617.802
Average Y = 647.247
Residual sum of squares = 73634.6
Regression sum of squares = 1.5172E+007
Coef of determination, R-squared = 0.99517
Residual mean square, sigma-hat-sq'd = 1248.04

6/1/04-9/30/04
Equation Y = 0.4055074593 * X + 133.947979
Number of data points used = 72
Average X = 111.049
Average Y = 178.979
Residual sum of squares = 13154.9
Regression sum of squares = 9382.23
Coef of determination, R-squared = 0.416301
Residual mean square, sigma-hat-sq'd = 187.928

Figure 5.1.2. Relationship between Snelling Gage and Robinson Gage, Mean Daily Flows

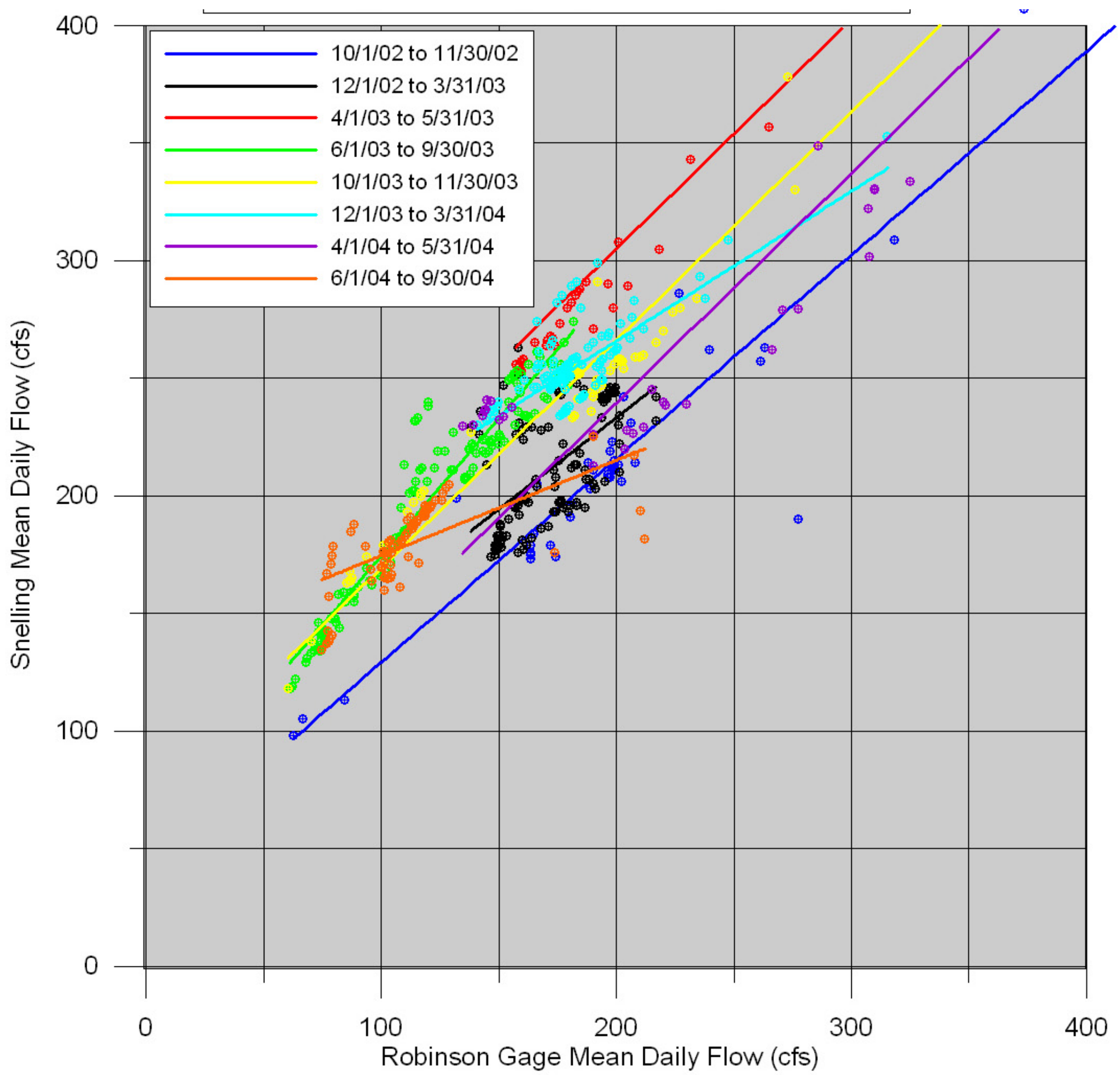


Figure 5.1.3. Same as Figure 5.1.2, 0 to 400cfs

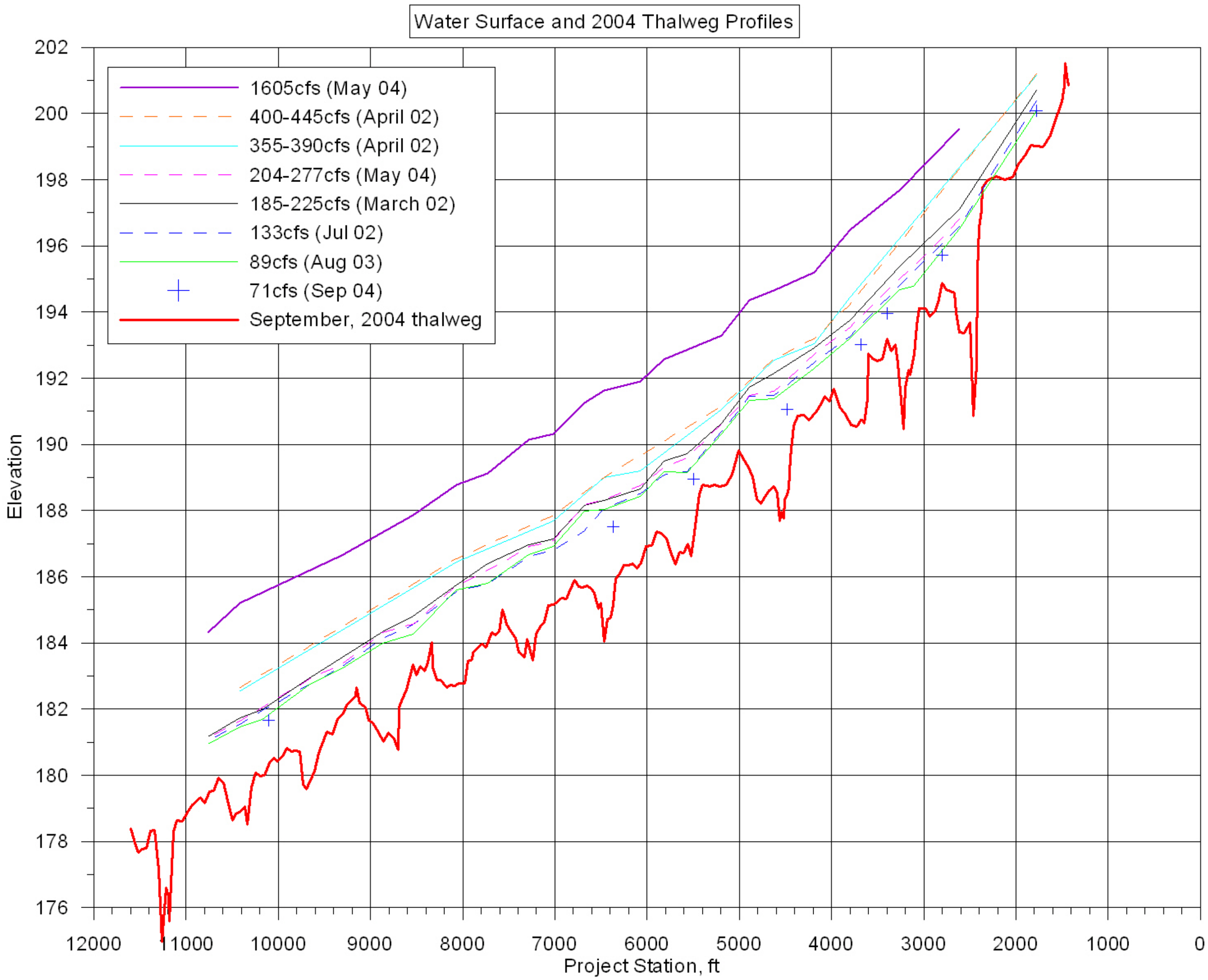


Figure 5.1.4. Surveyed Water Surface Profiles and 2004 Channel Thalweg

Figure 5.1.4

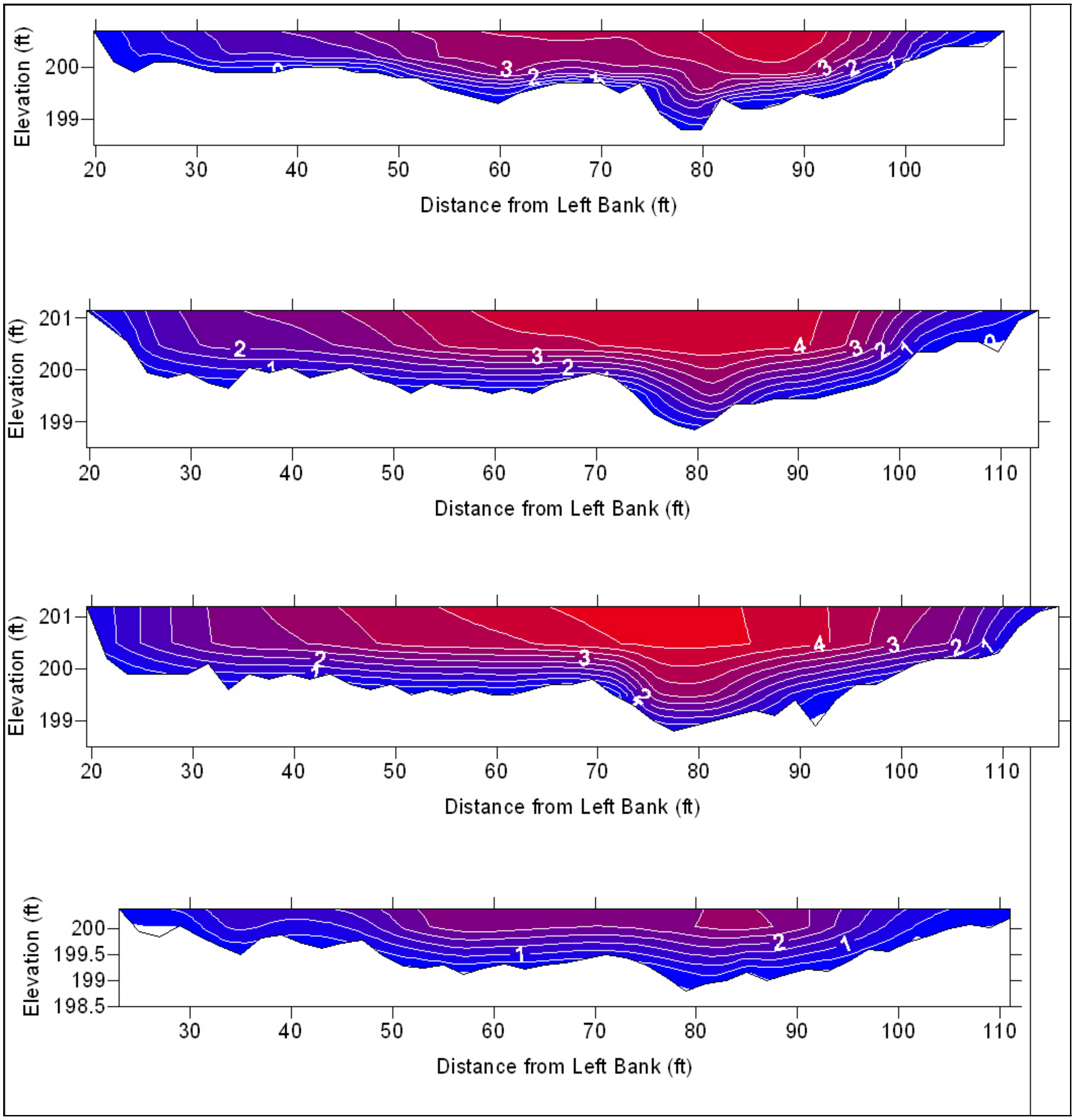


Figure 5.1.5. Section 1 Velocity Profile on 3/21/02 (225cfs), 4/16/02 (381cfs), 4/23/02 (451cfs), and 7/10/02 (174cfs)

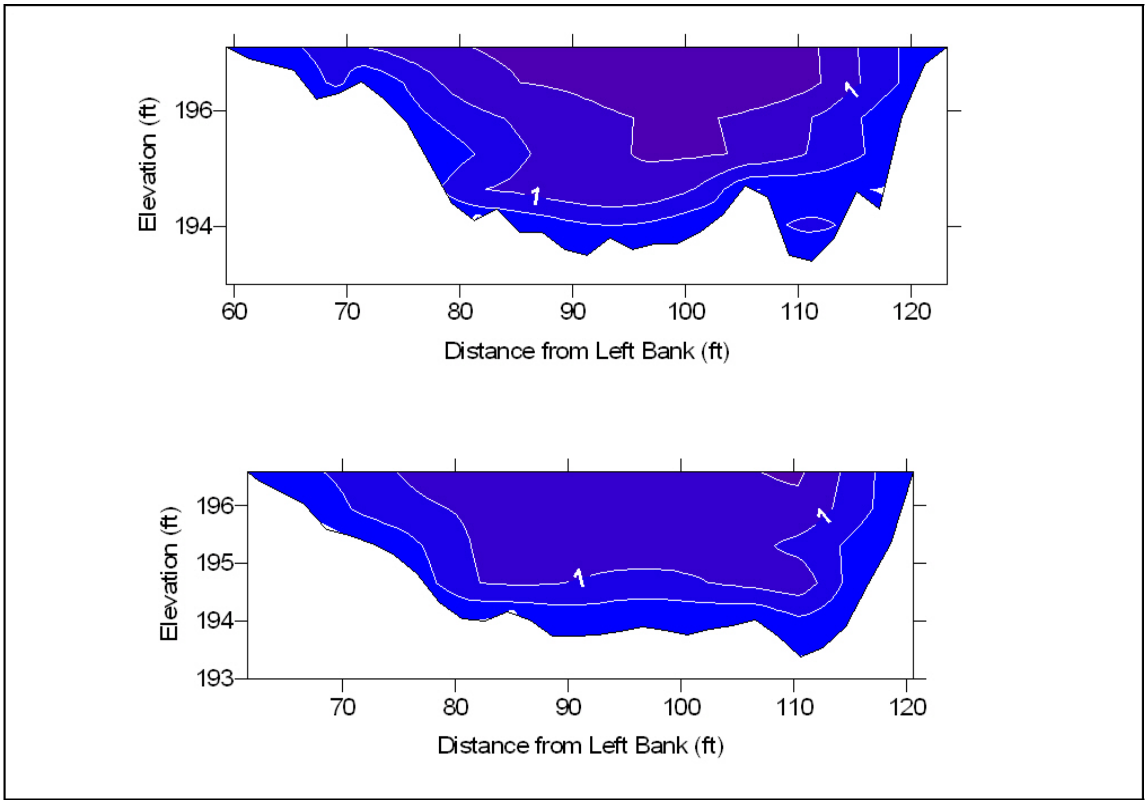


Figure 5.1.6. Section 2 Velocity Profile on 3/21/02 (225cfs) and 7/10/02 (174cfs)

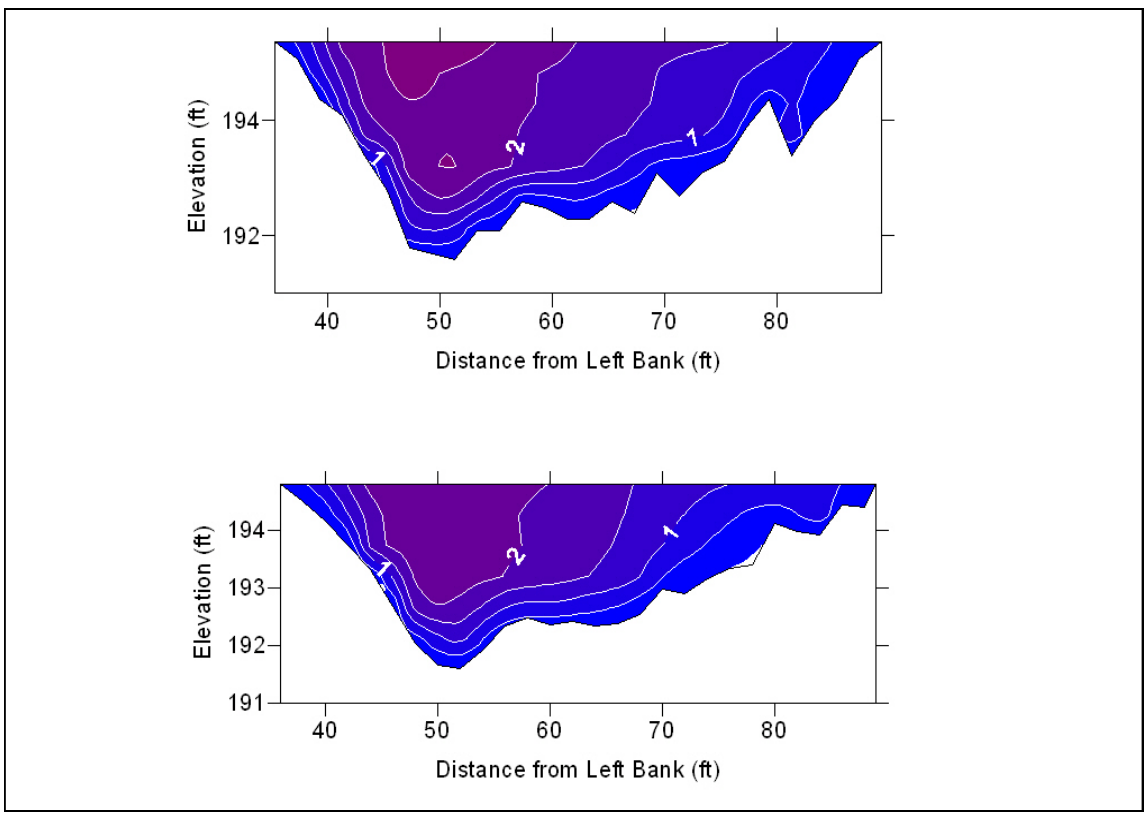


Figure 5.1.7. Section 4 Velocity Profile on 3/25/02 (225cfs) and 7/10/02 (174cfs)

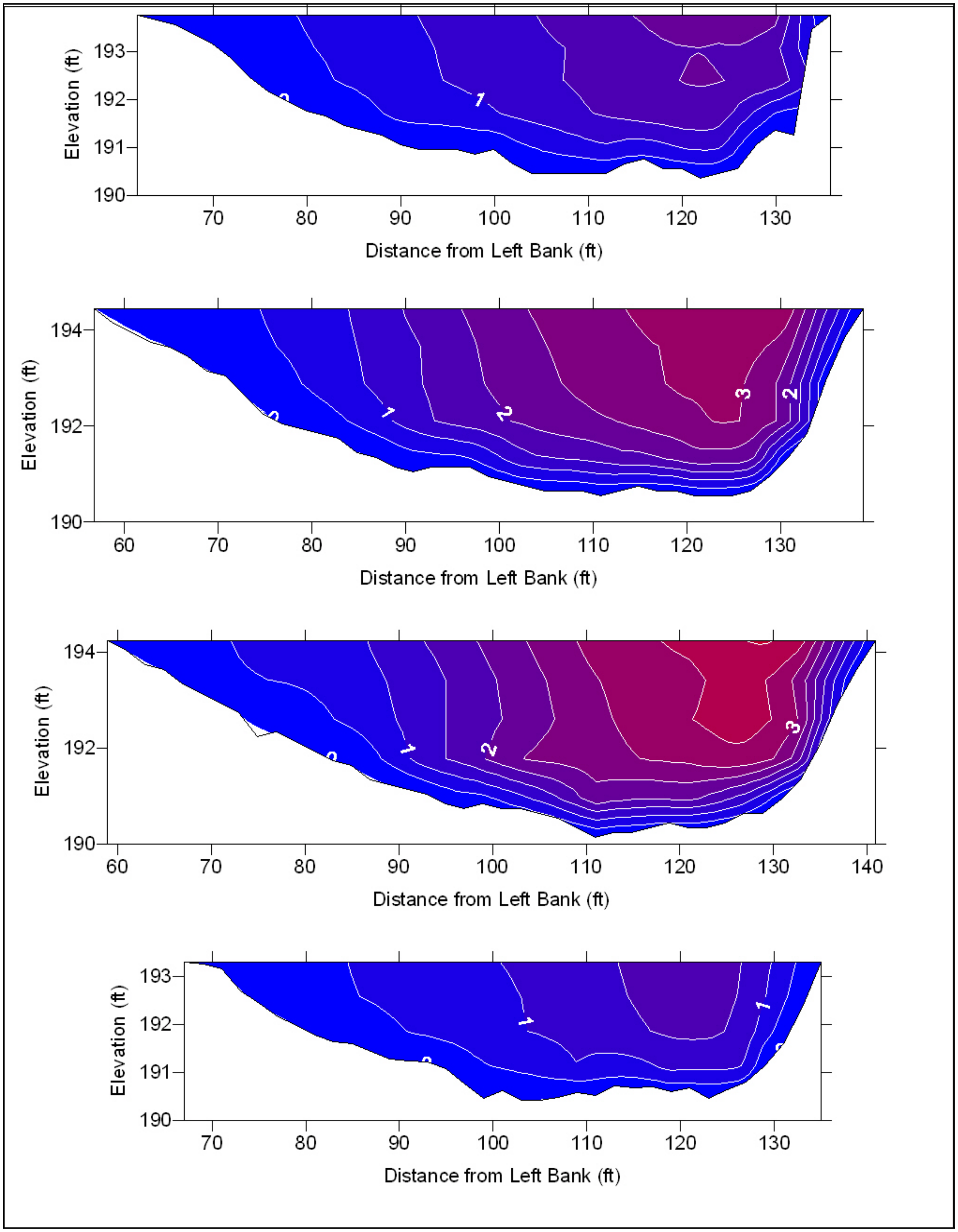


Figure 5.1.8. Section 5 Velocity Profile on 3/25/02 (225cfs), 4/17/02 (408cfs), 4/23/02 (451cfs) and 7/10/02 (174cfs)

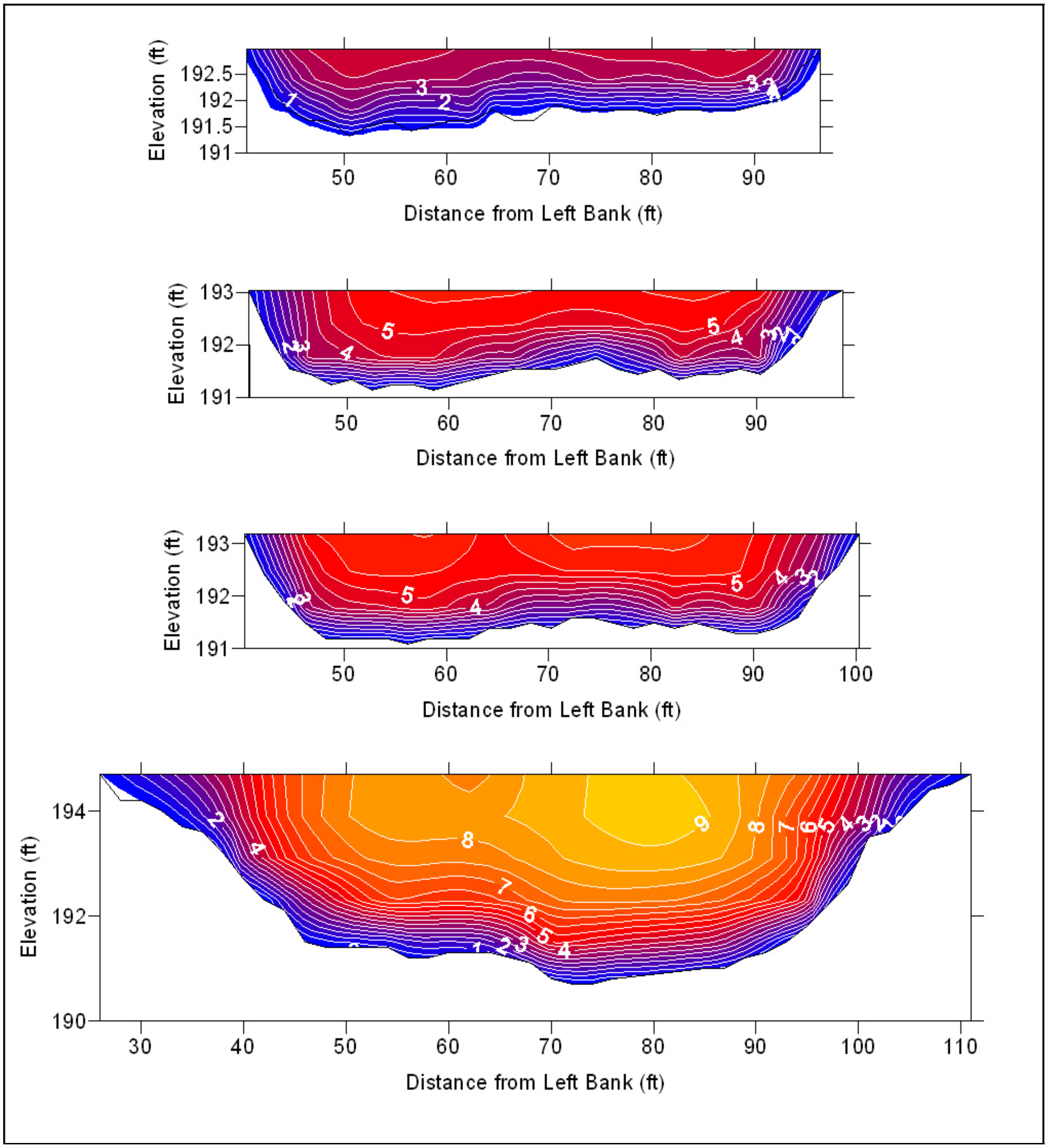


Figure 5.1.9. Section 6 Velocity Profile on 3/25/02 (225cfs), 4/16/02 (381cfs), 4/23/02 (451cfs) and 5/2/02 (1,394cfs)

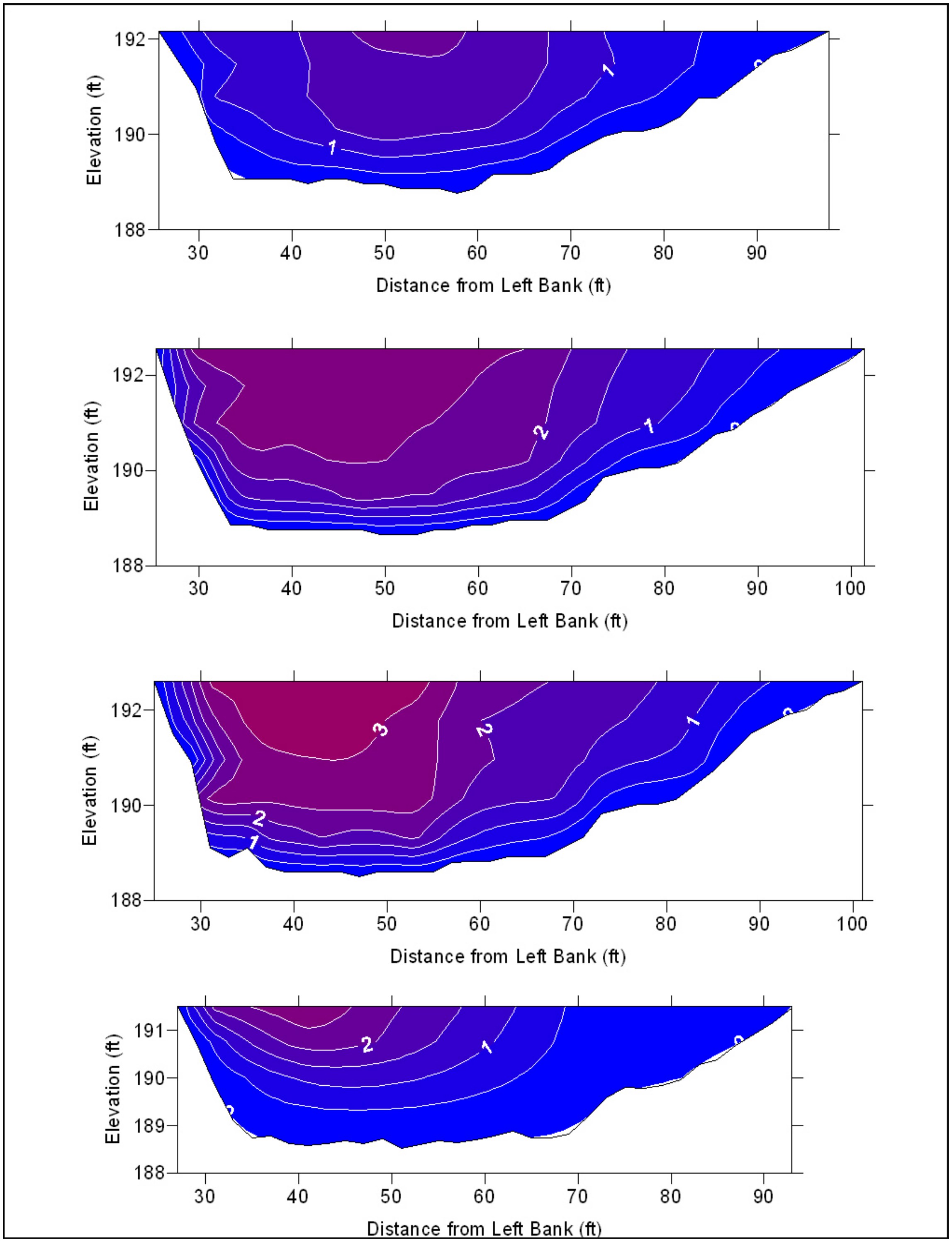


Figure 5.1.10. Section 7 Velocity Profile on 3/25/02 (225cfs), 4/17/02 (408cfs), 4/25/02 (439cfs) and 7/11/02 (184cfs)

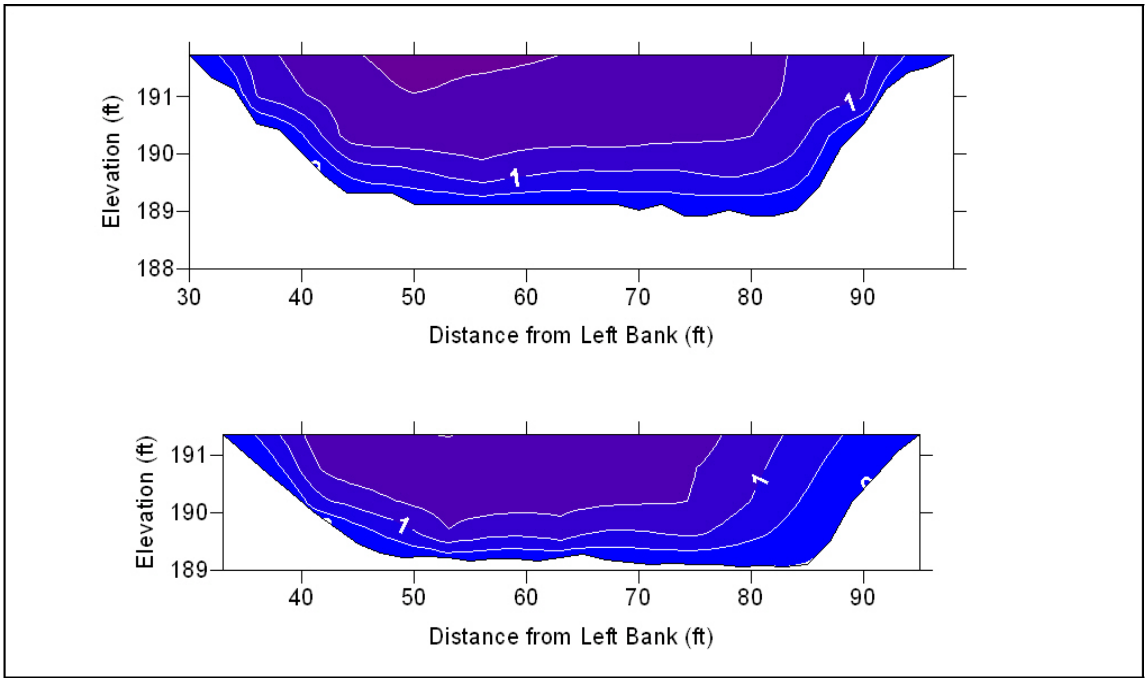


Figure 5.1.11. Section 8 Velocity Profile on 3/26/02 (231cfs) and 7/11/02 (184cfs)

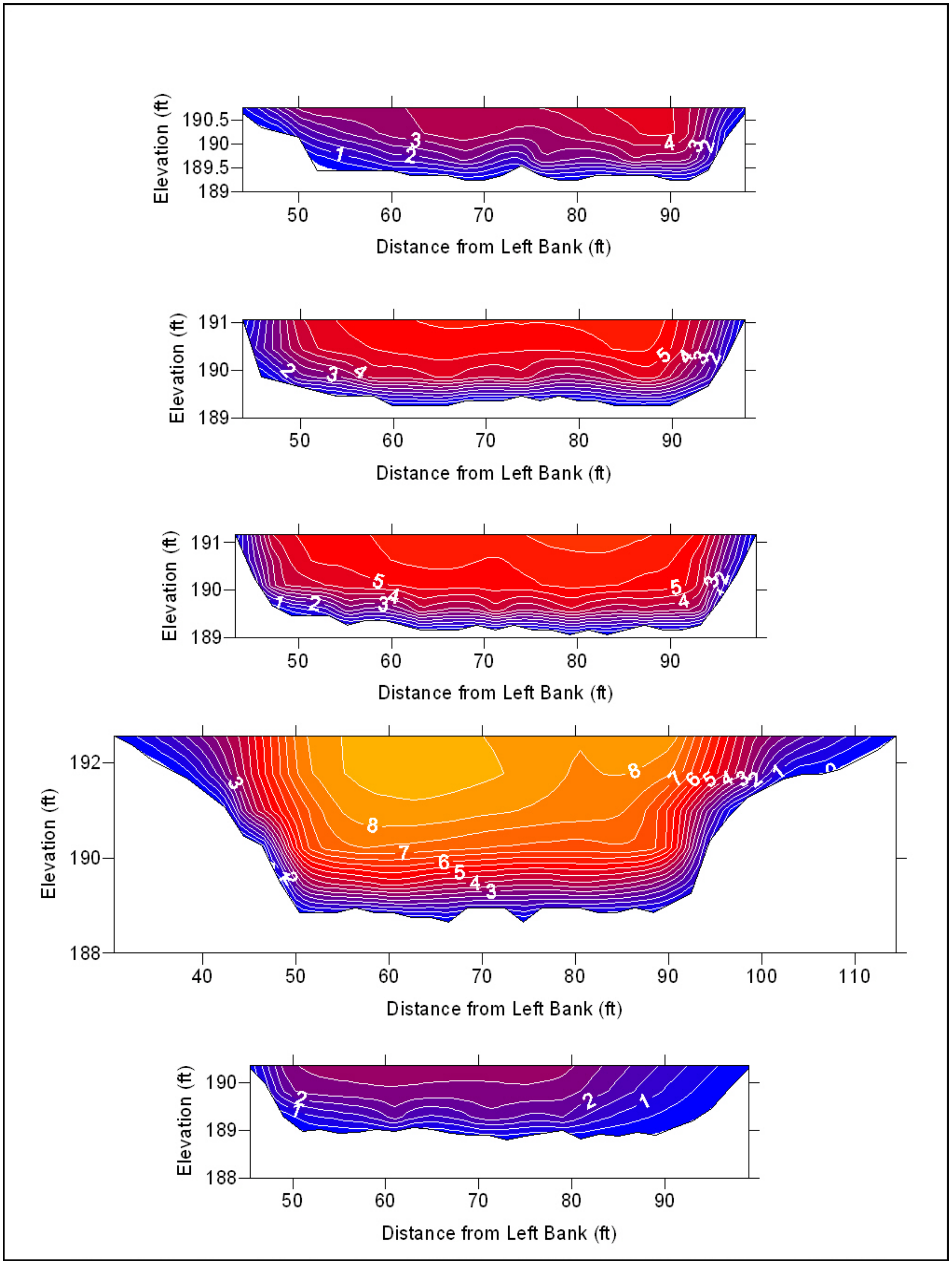


Figure 5.1.12. Section 9 Velocity Profile on 3/26/02 (231cfs), 4/16/02 (381cfs), 4/23/02 (451cfs), 5/02/02 (1,394cfs) and 7/11/02 (184cfs)

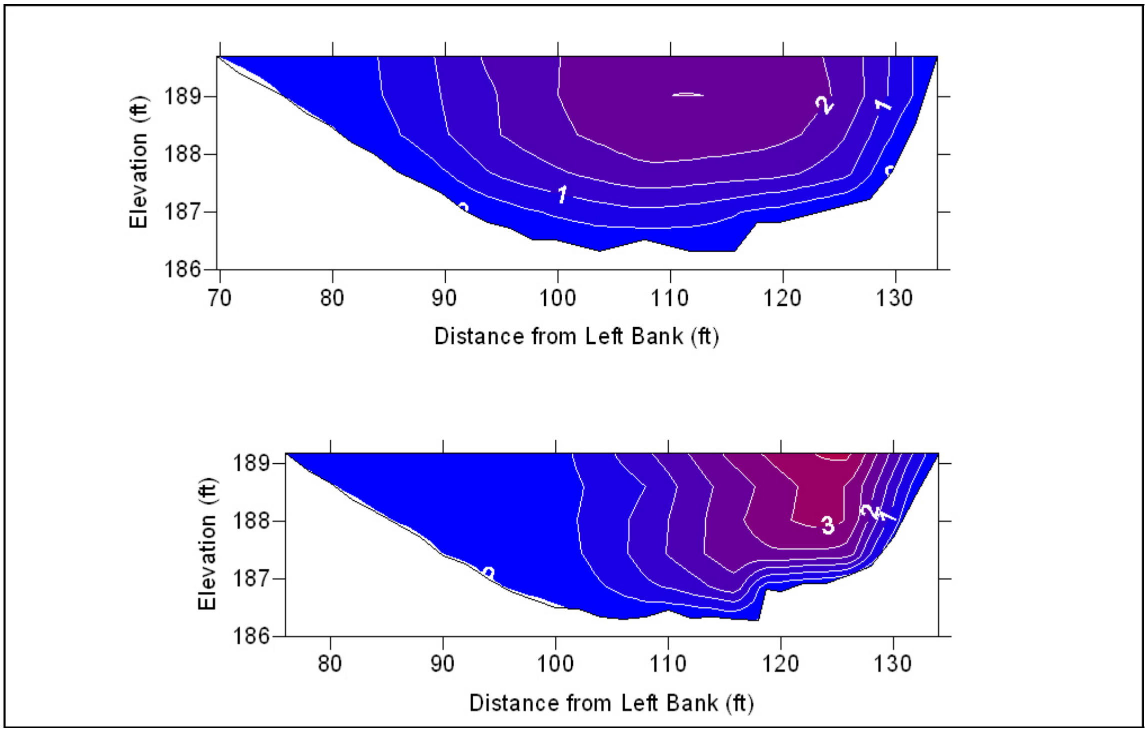


Figure 5.1.13. Section 10 Velocity Profile on 3/26/02 (231cfs) and 7/11/02 (184cfs)

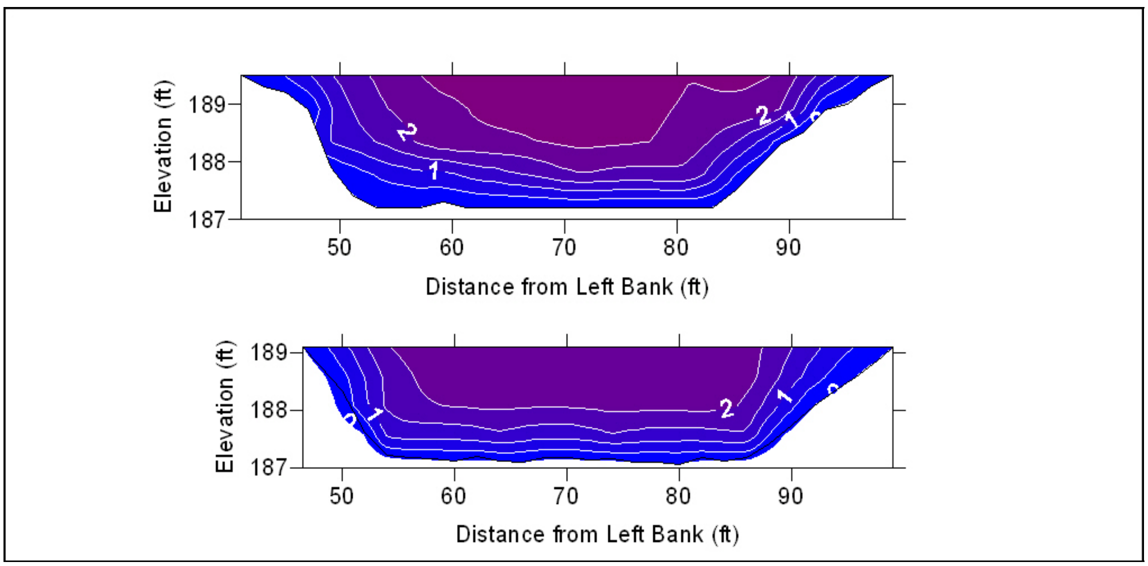


Figure 5.1.14. Section 11 Velocity Profile on 3/26/02 (231cfs) and 7/11/02 (184cfs)

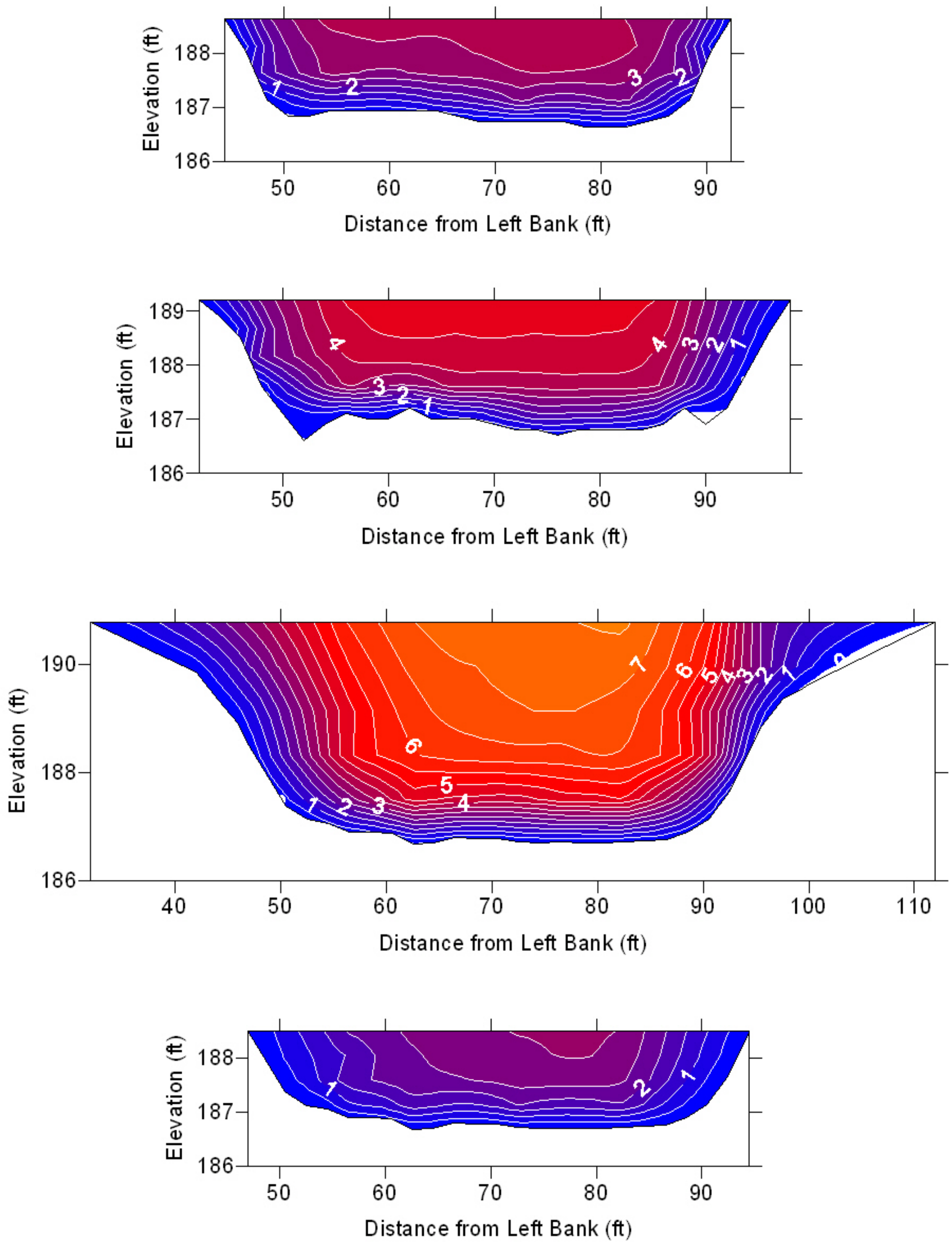


Figure 5.1.15. Section 12 Velocity Profile on 3/26/02 (231cfs), 4/16/02 (381cfs), 5/08/02 (979cfs) and 7/11/02 (184cfs)

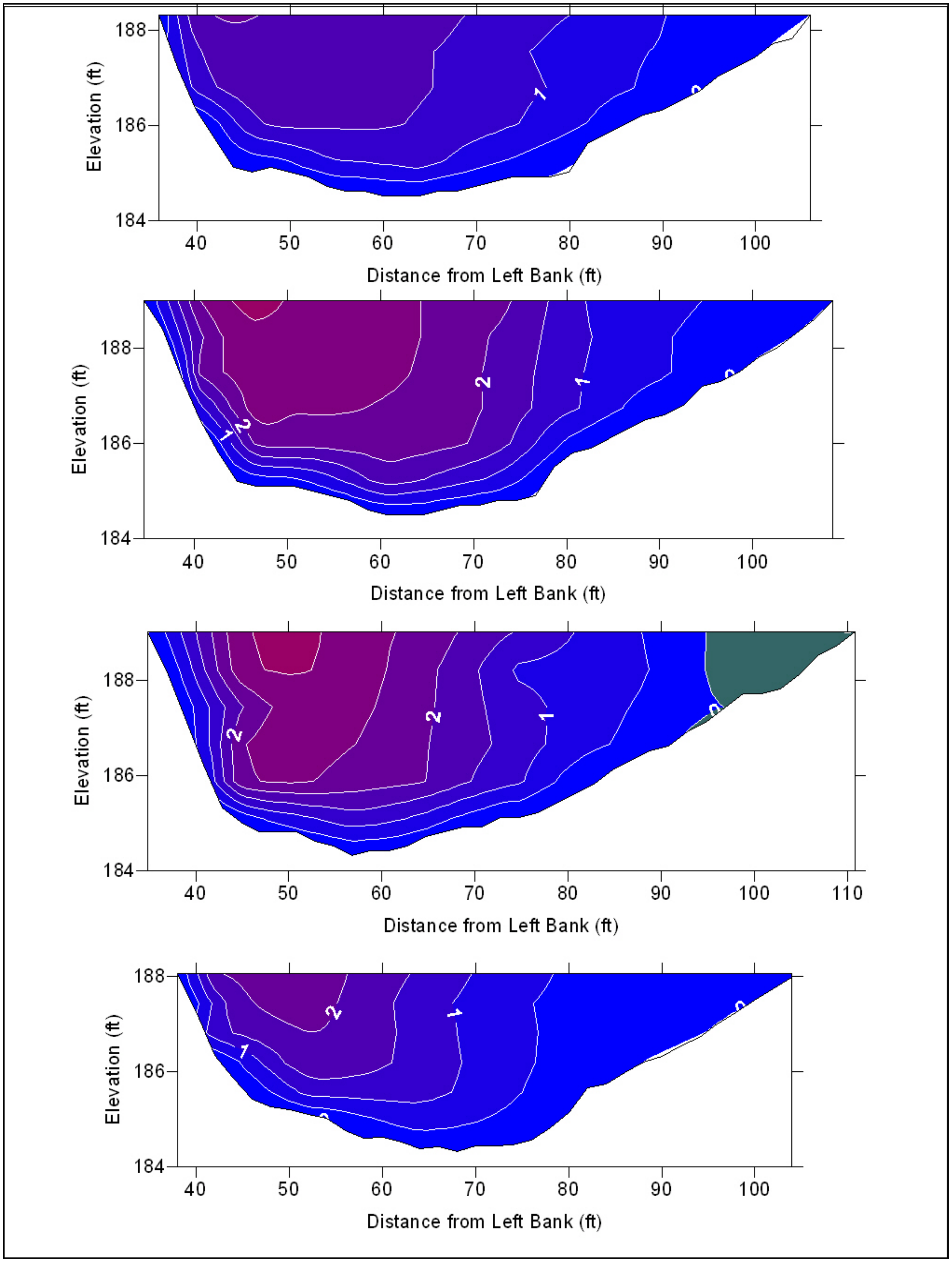


Figure 5.1.16. Section 13 Velocity Profile on 3/26/02 (231cfs), 4/17/02 (408cfs), 4/25/02 (439cfs) and 7/11/02 (184cfs)

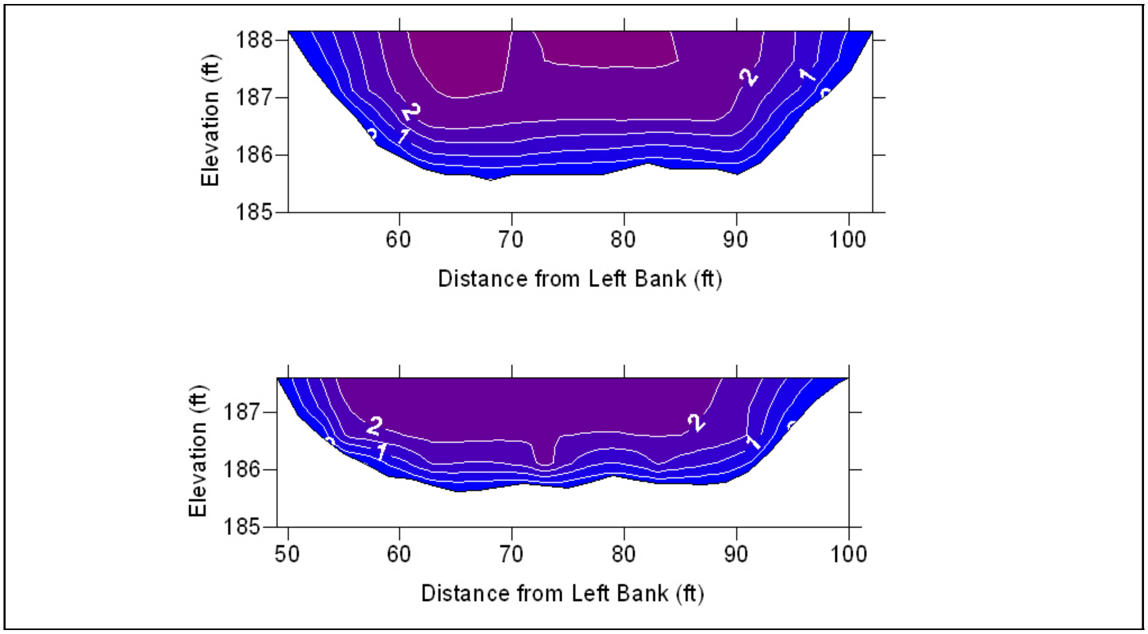


Figure 5.1.17. Section 14 Velocity Profile on 3/27/02 (220cfs) and 7/11/02 (184cfs)

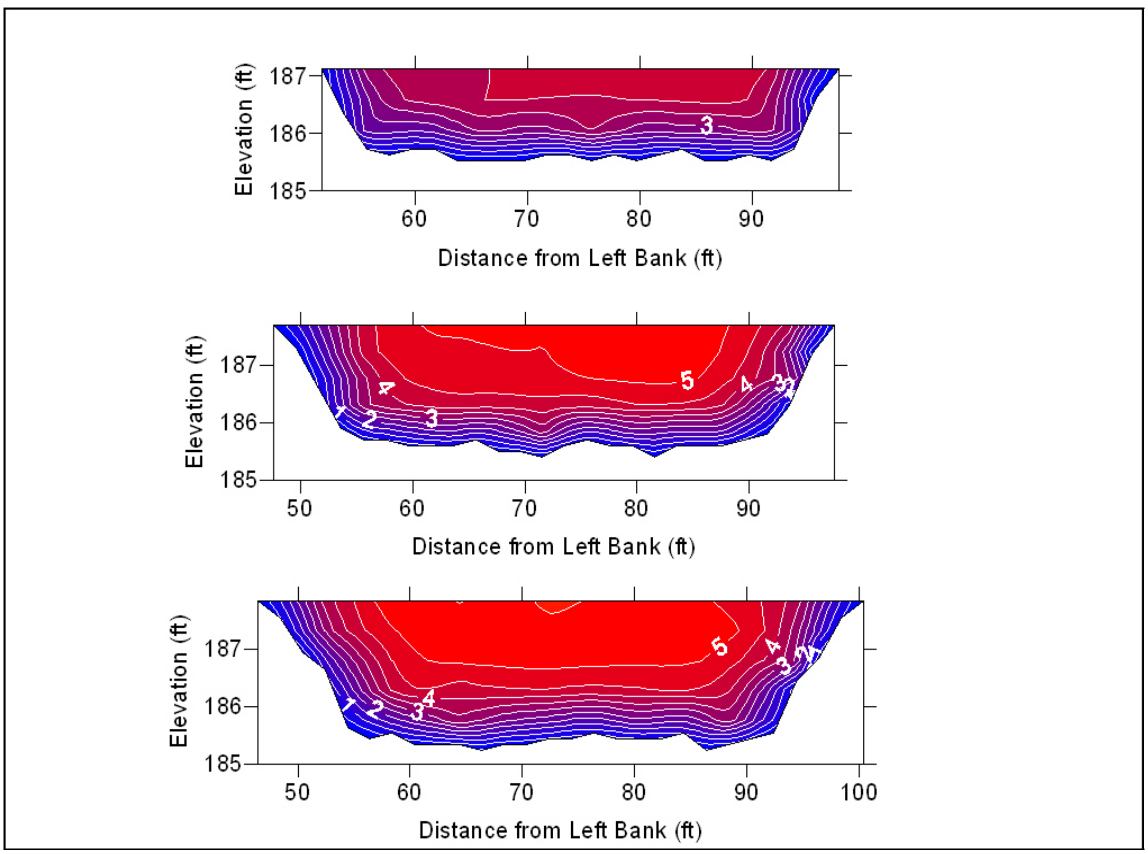


Figure 5.1.18. Section 15 Velocity Profile on 3/27/02 (220cfs), 4/16/02 (381cfs), 4/23/02 (451cfs)

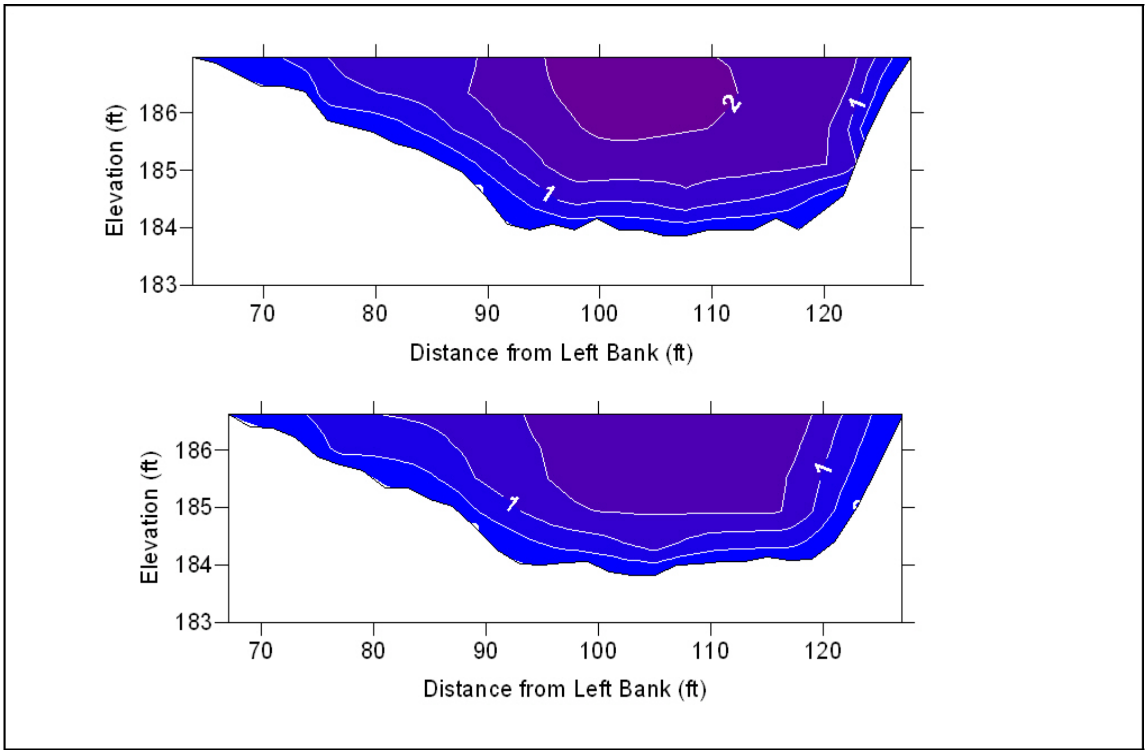


Figure 5.1.19. Section 16 Velocity Profile on 3/27/02 (220cfs) and 7/11/02 (184cfs)

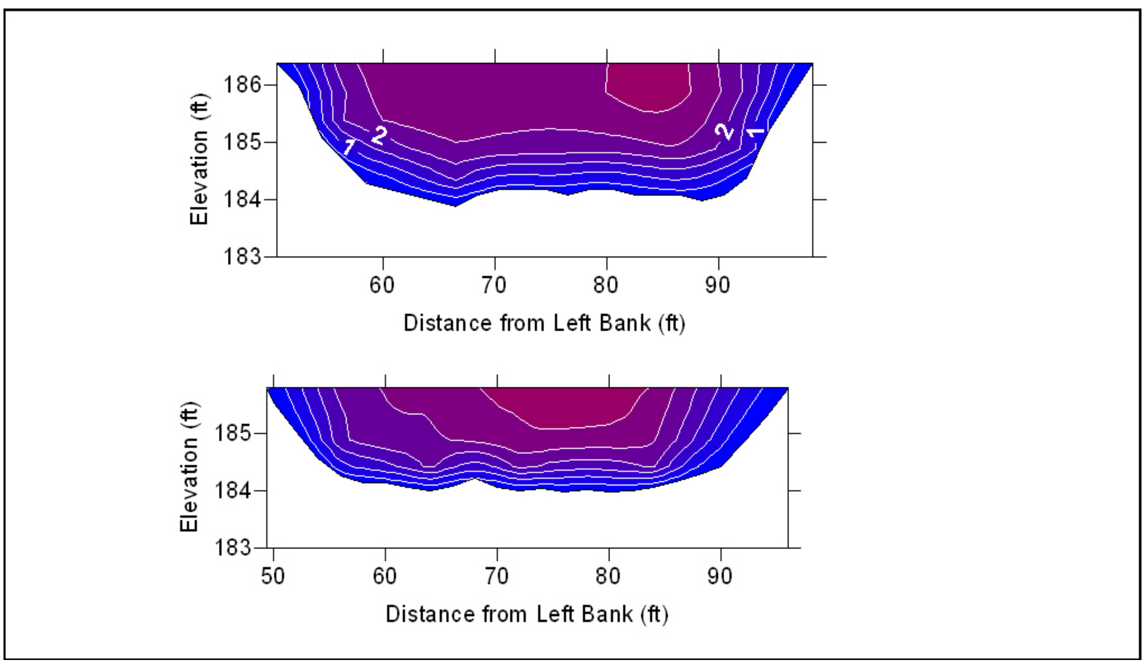


Figure 5.1.20. Section 17 Velocity Profile on 3/27/02 (220cfs) and 7/11/02 (184cfs)

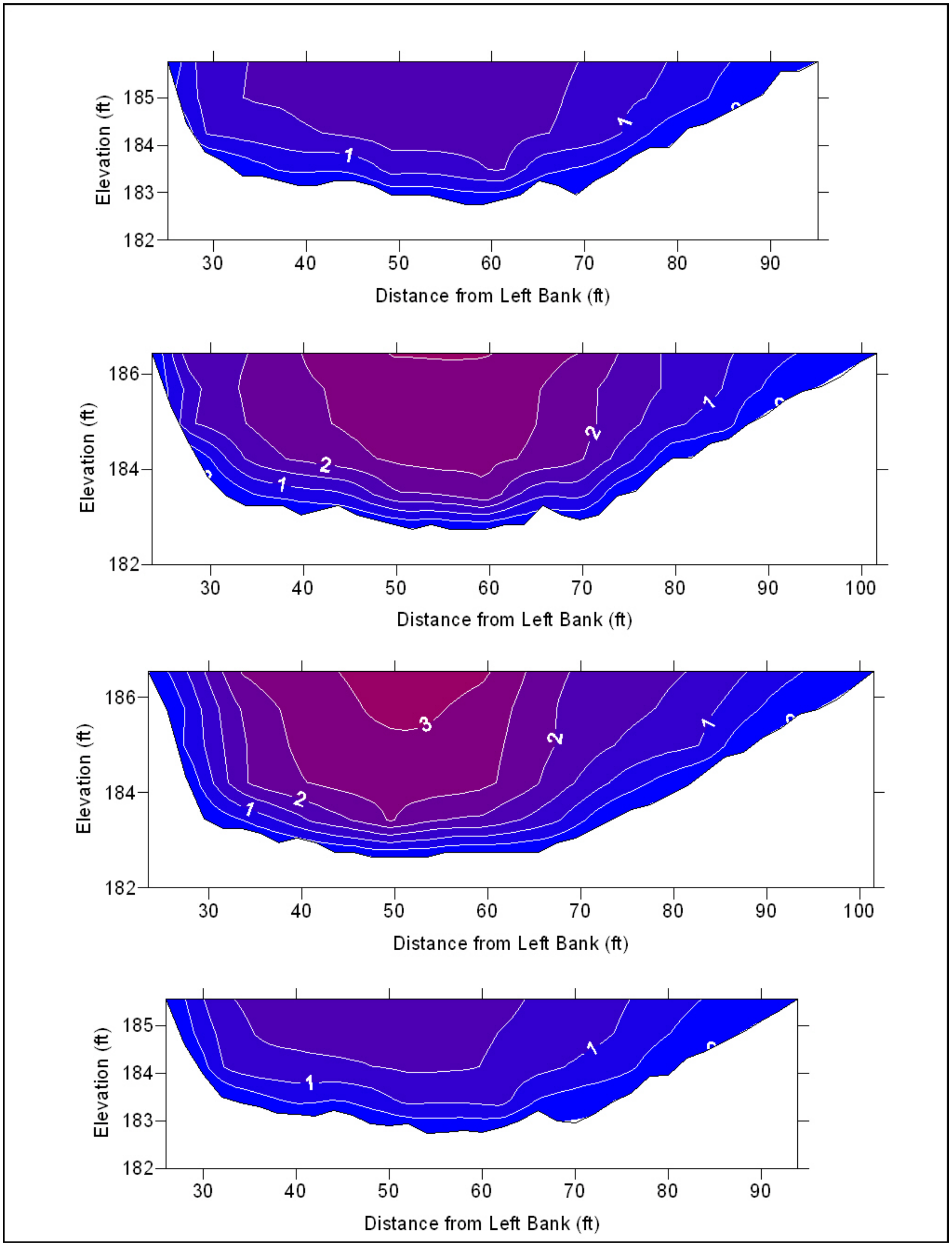


Figure 5.1.21. Section 18 Velocity Profile on 3/27/02 (220cfs), 4/17/02 (408cfs), 4/25/02 (439cfs) and 7/15/02 (177cfs)

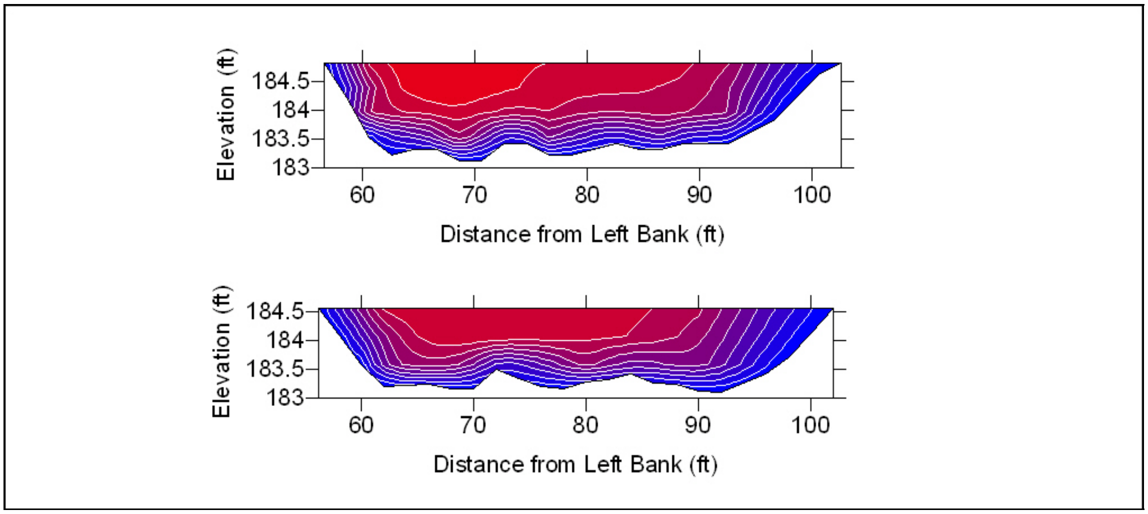


Figure 5.1.22. Section 19 Velocity Profile on 3/27/02 (220cfs) and 7/15/02 (177cfs)

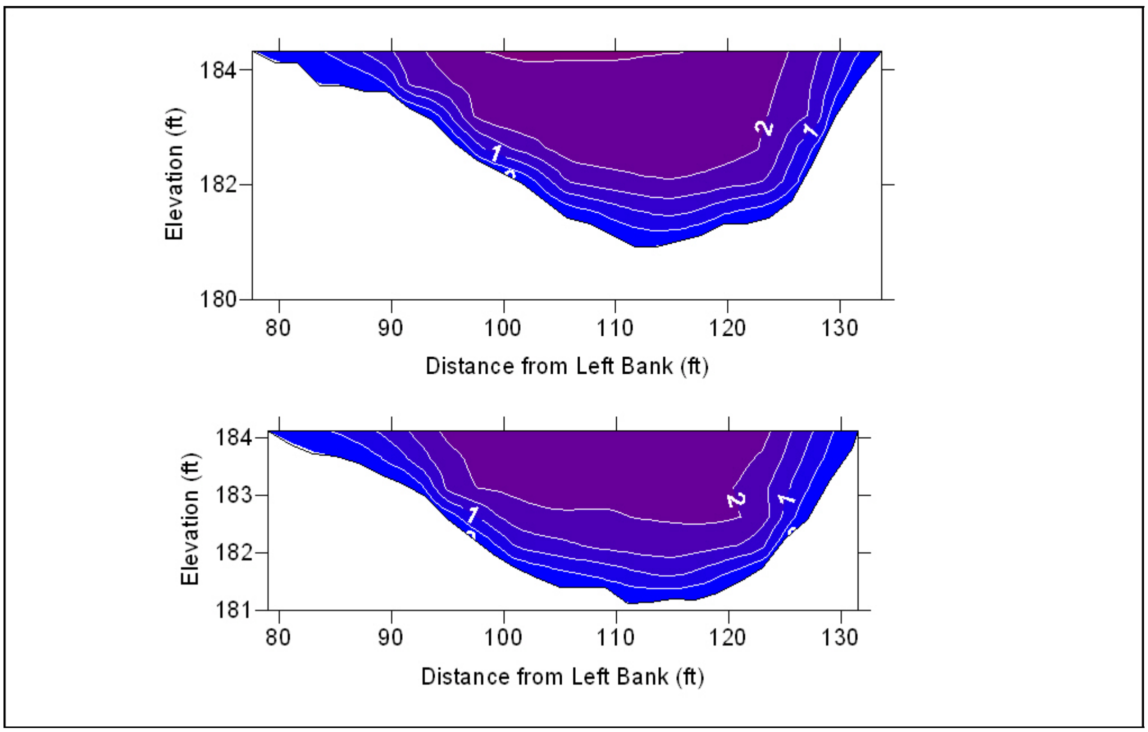


Figure 5.1.23. Section 20 Velocity Profile on 3/27/02 (220cfs) and 7/15/02 (177cfs)

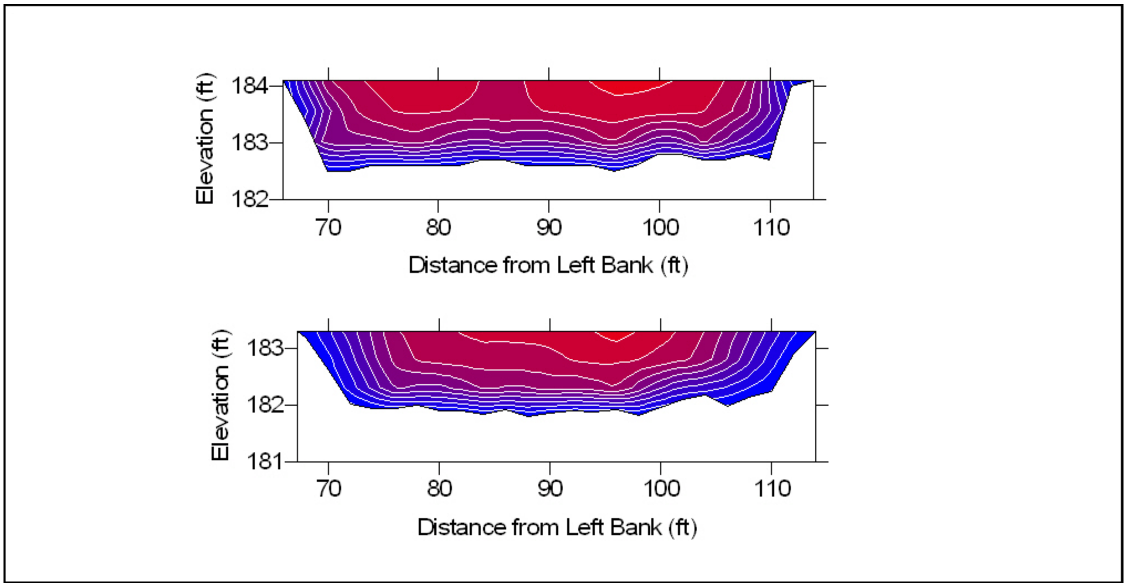


Figure 5.1.24. Section 21 Velocity Profile on 3/27/02 (220cfs) and 7/15/02 (177cfs)

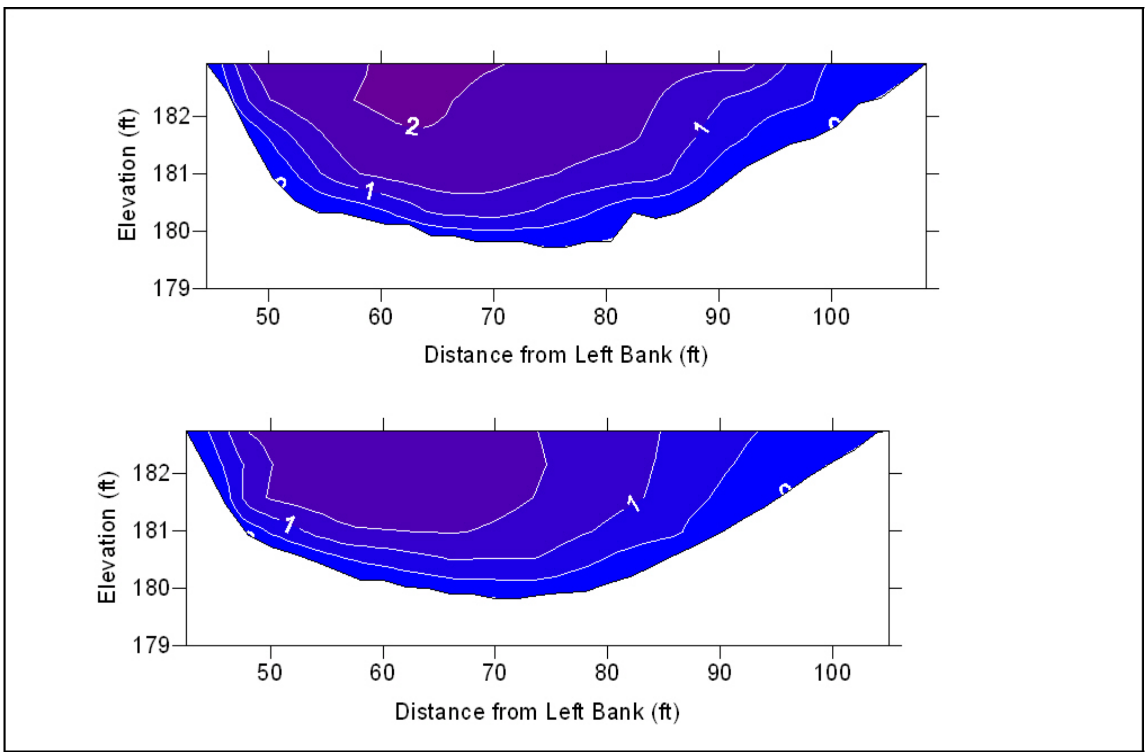


Figure 5.1.25. Section 22 Velocity Profile on 3/28/02 (220cfs) and 7/15/02 (177cfs)

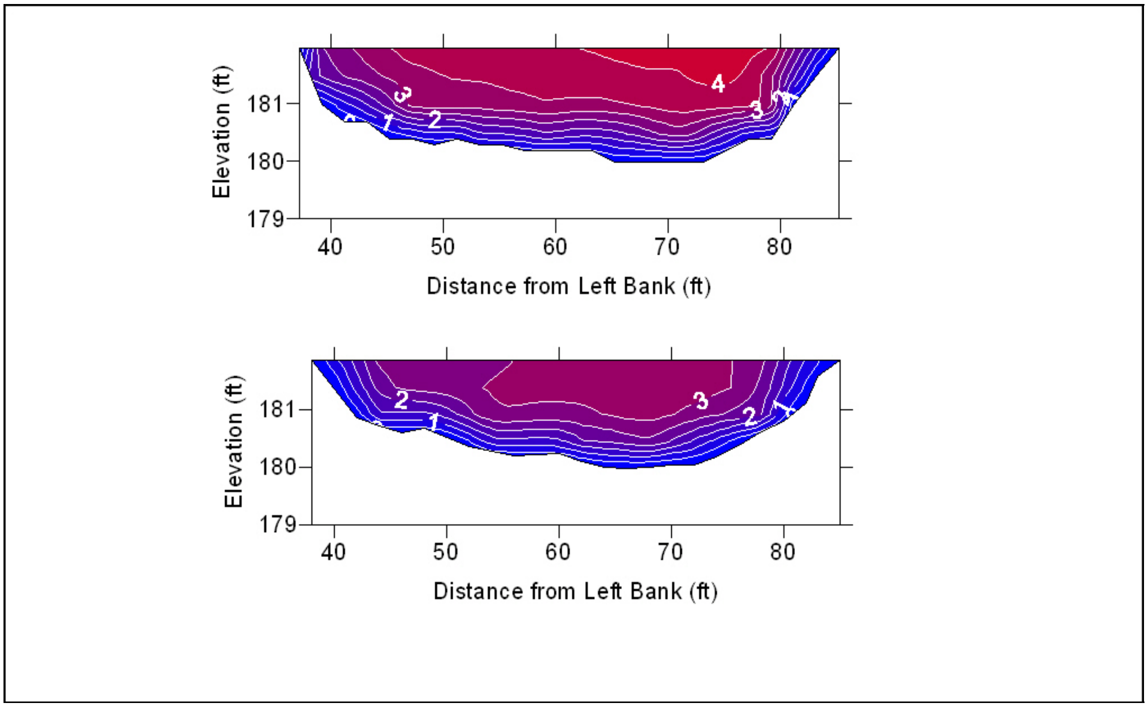


Figure 5.1.26. Section 23 Velocity Profile on 3/28/02 (220cfs) and 7/15/02 (177cfs)

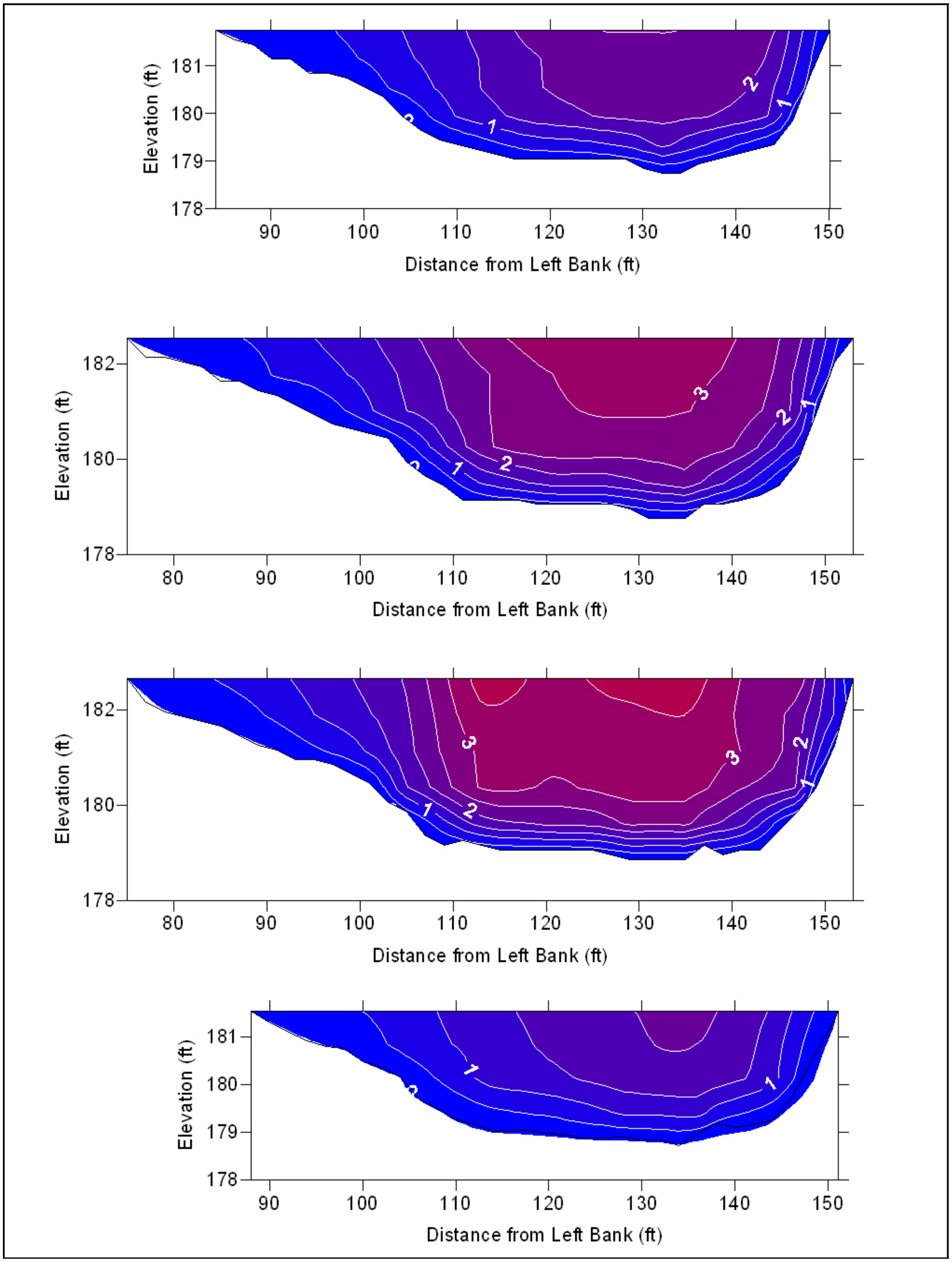


Figure 5.1.27. Section 24 Velocity Profile on 3/28/02 (220cfs), 4/17/02 (408cfs), 4/25/02 (439cfs) and 7/15/02 (177cfs)

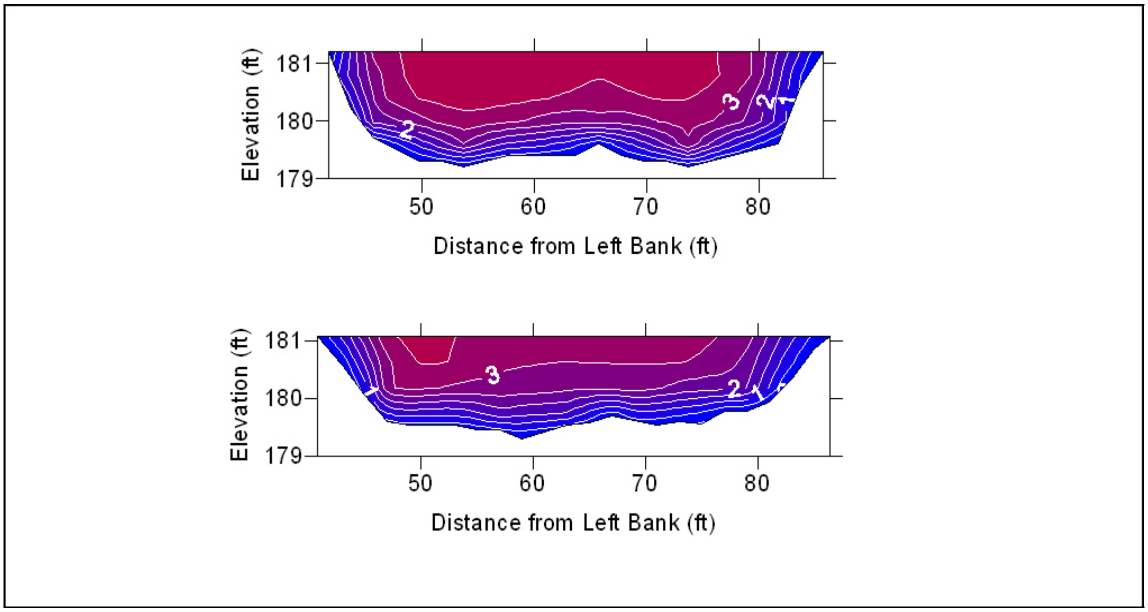


Figure 5.1.28. Section 25 Velocity Profile on 3/28/02 (220cfs) and 7/15/02 (177cfs)

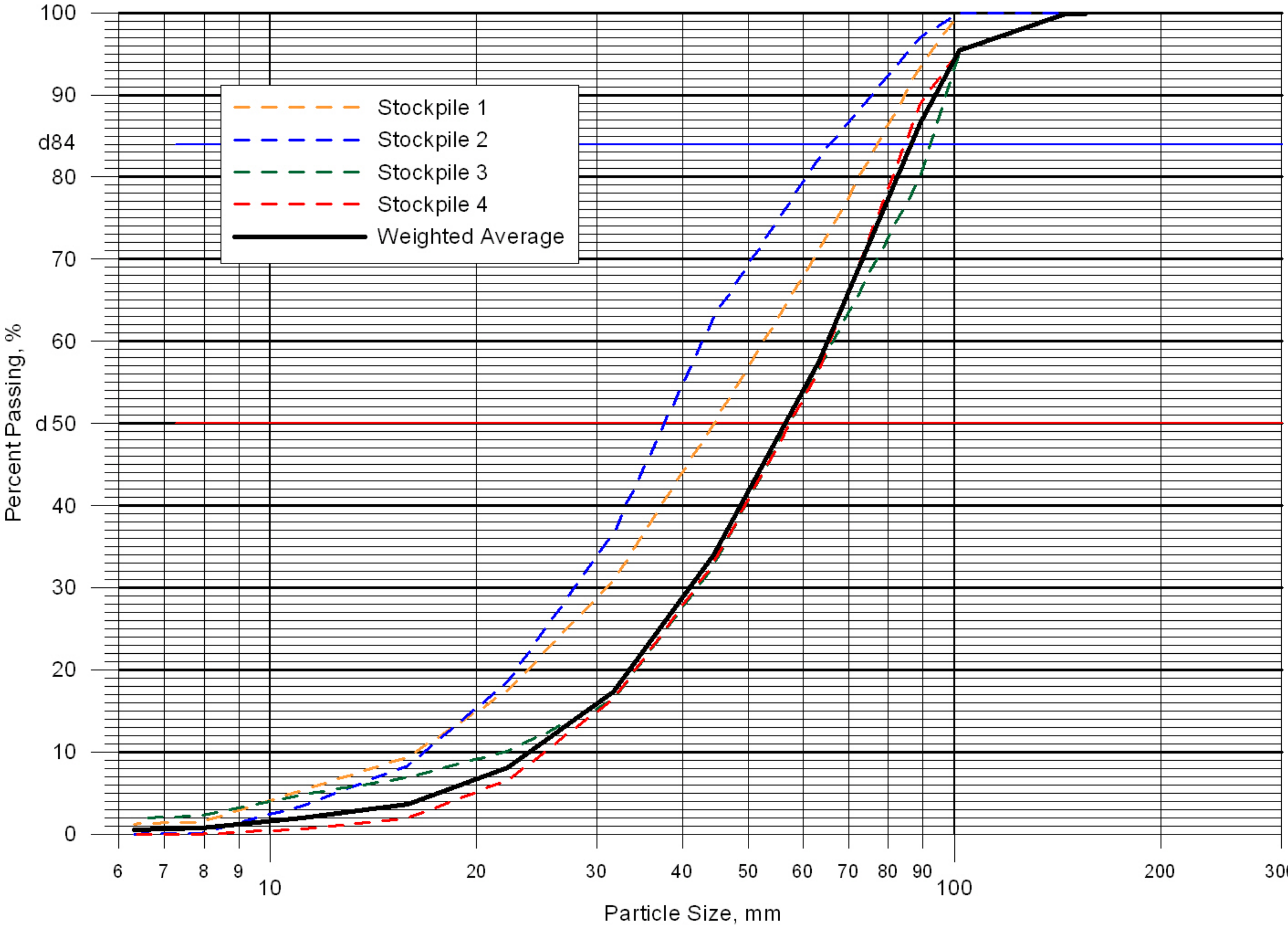


Figure 5.2.1. 2001 Bulk Sample Sieve Analysis Results, Pre-Placement Graded Material used in Constructed Channel

Figure 5.2.1

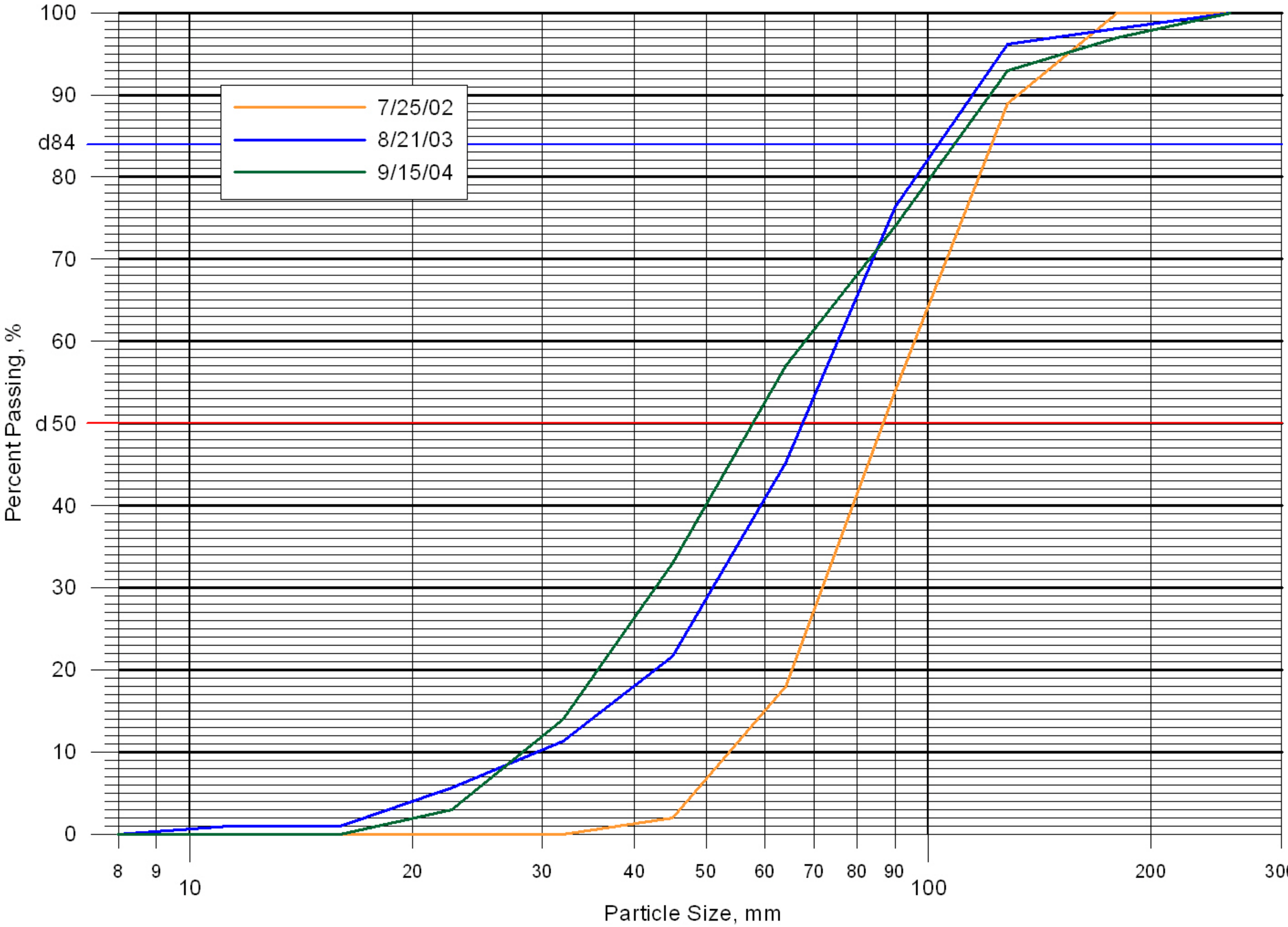


Figure 5.2.2. Pebble Count Results, Section 1 (Riffle)

Figure 5.2.2

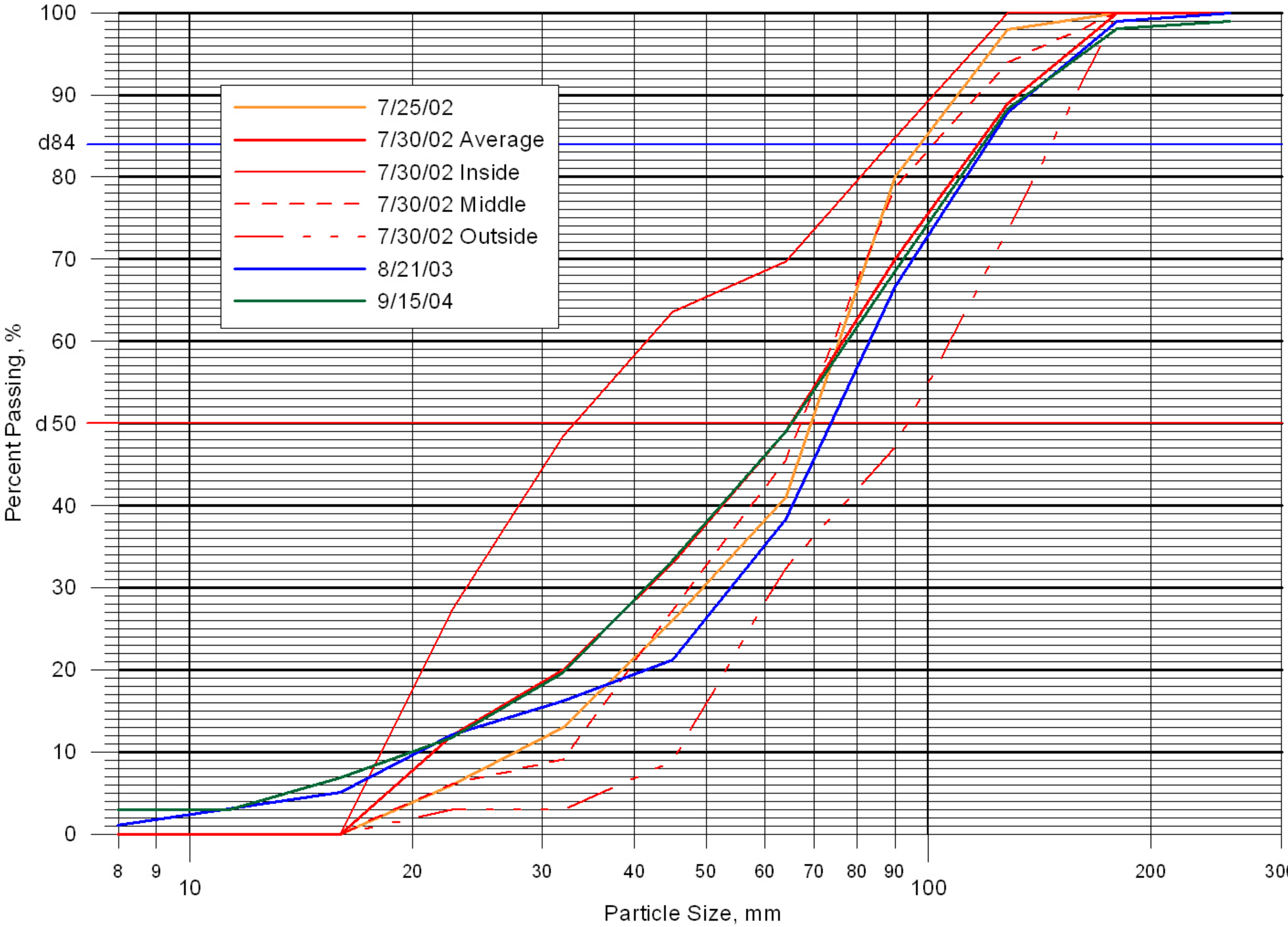


Figure 5.2.3. Pebble Count Results, Section 2 (Pool)

Figure 5.2.3

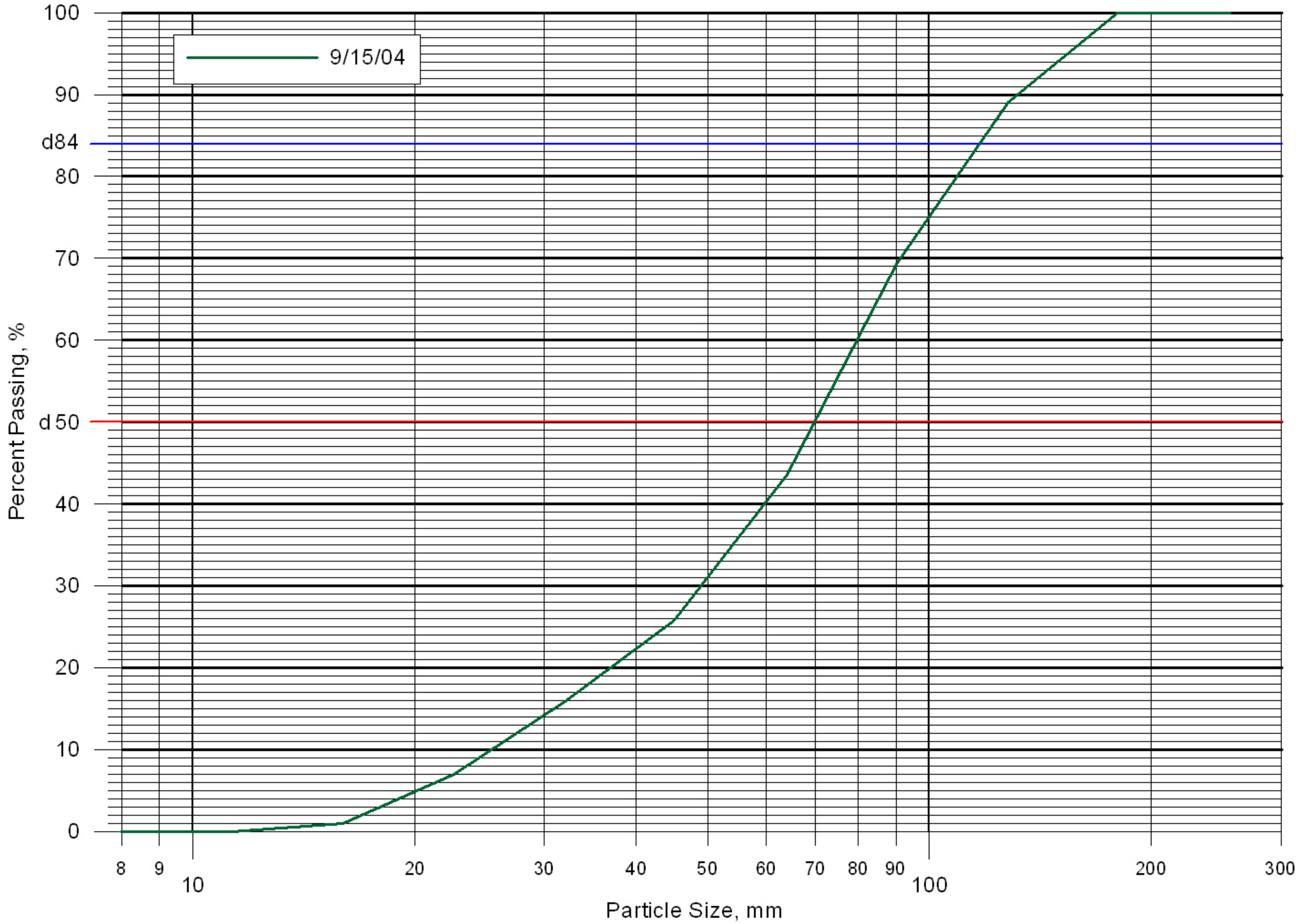


Figure 5.2.4. Pebble Count Results, Section 2b (Riffle)

Figure 5.2.4

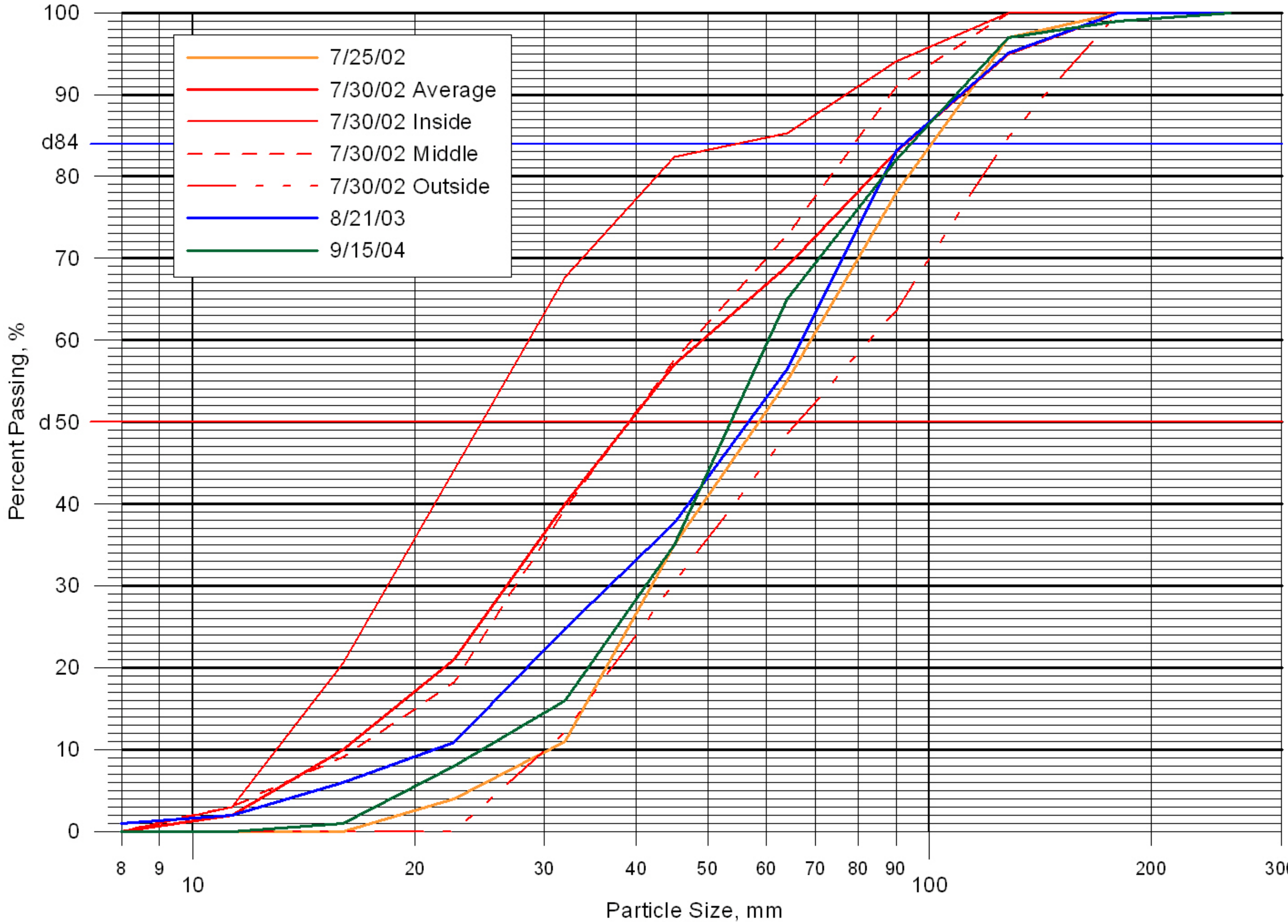


Figure 5.2.5. Pebble Count Results, Section 3 (Pool)

Figure 5.2.5

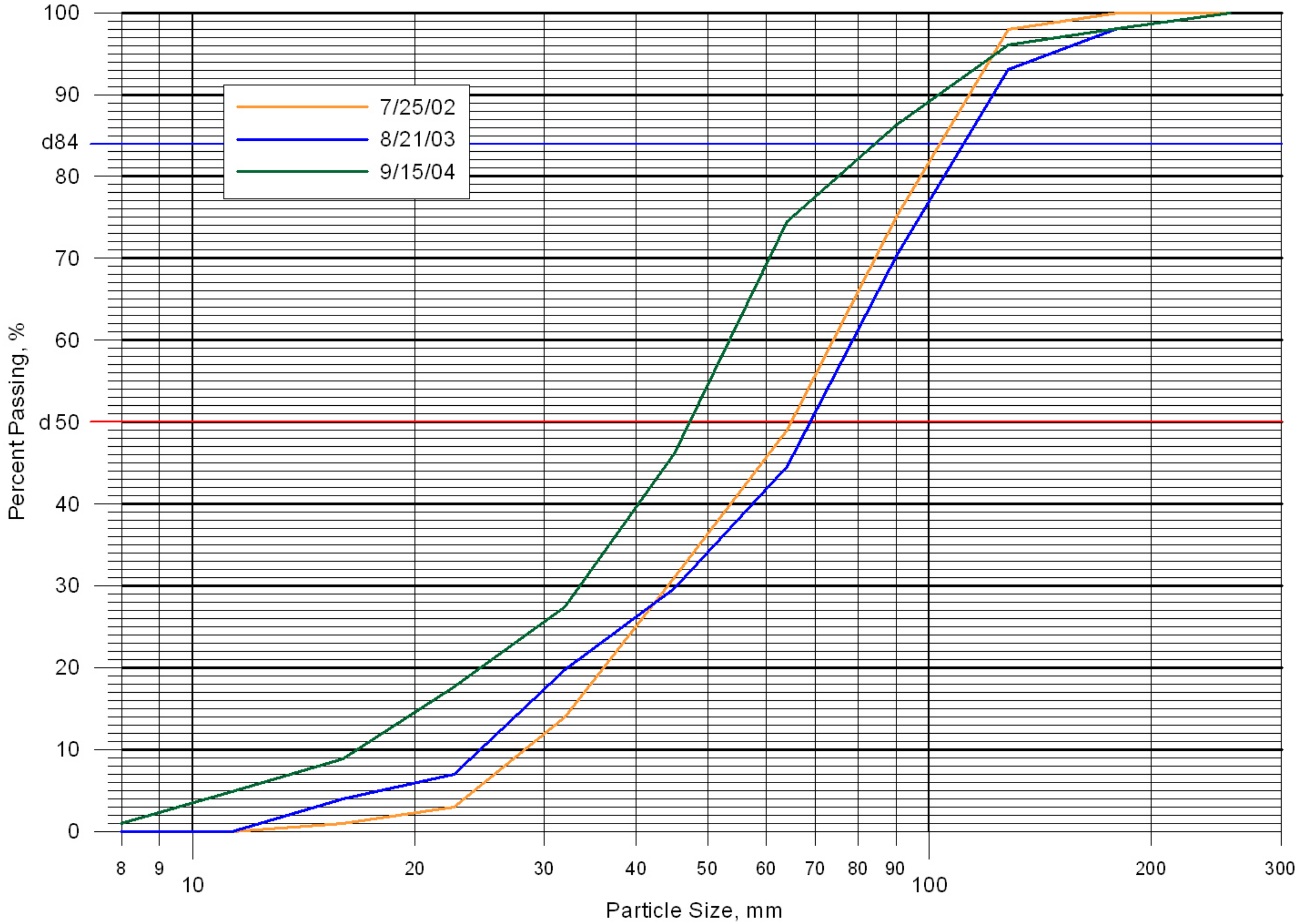


Figure 5.2.6. Pebble Count Results, Section 4 (Transition)

Figure 5.2.6

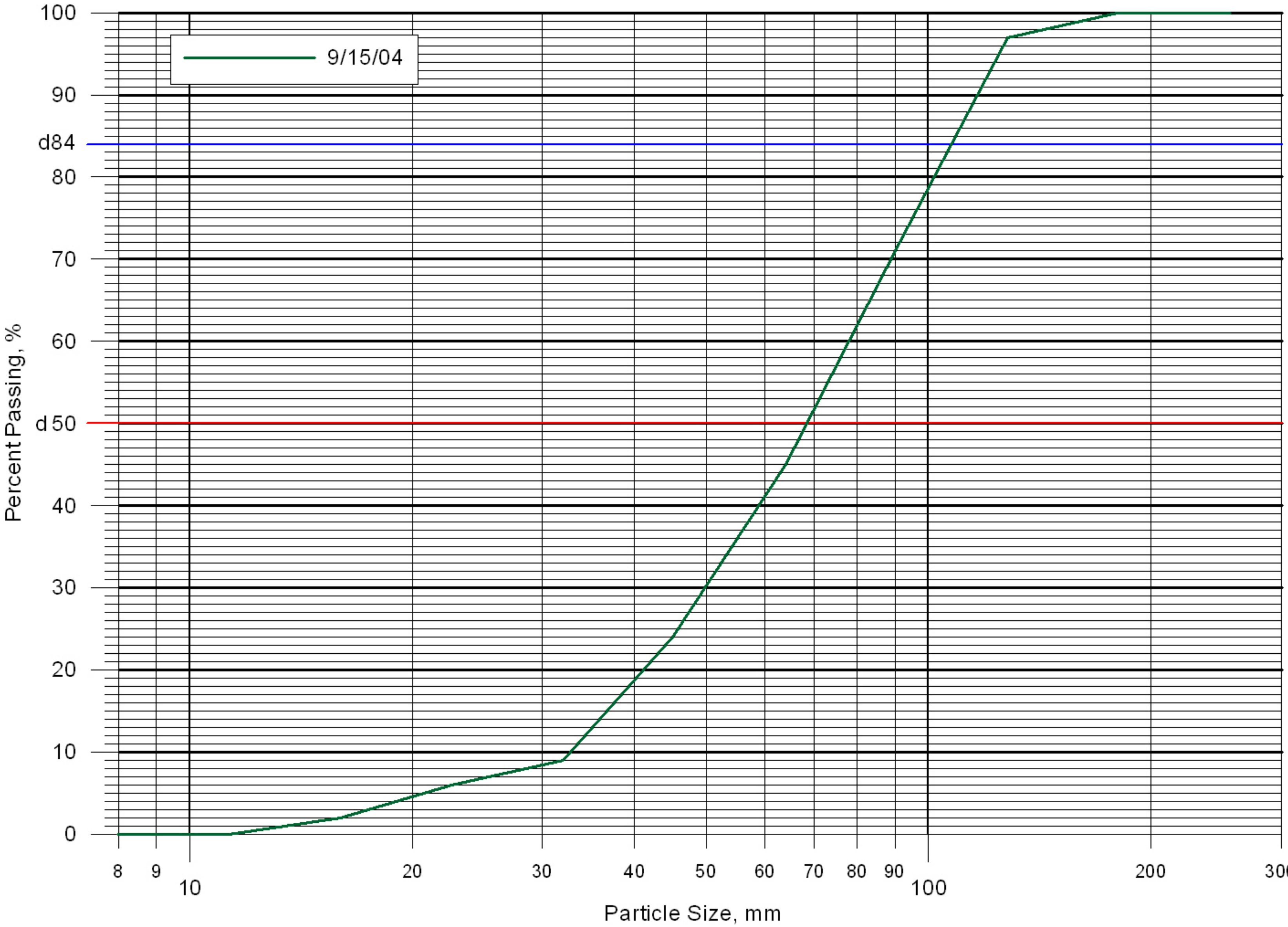


Figure 5.2.7. Pebble Count Results, Section 4b (Riffle)

Figure 5.2.7

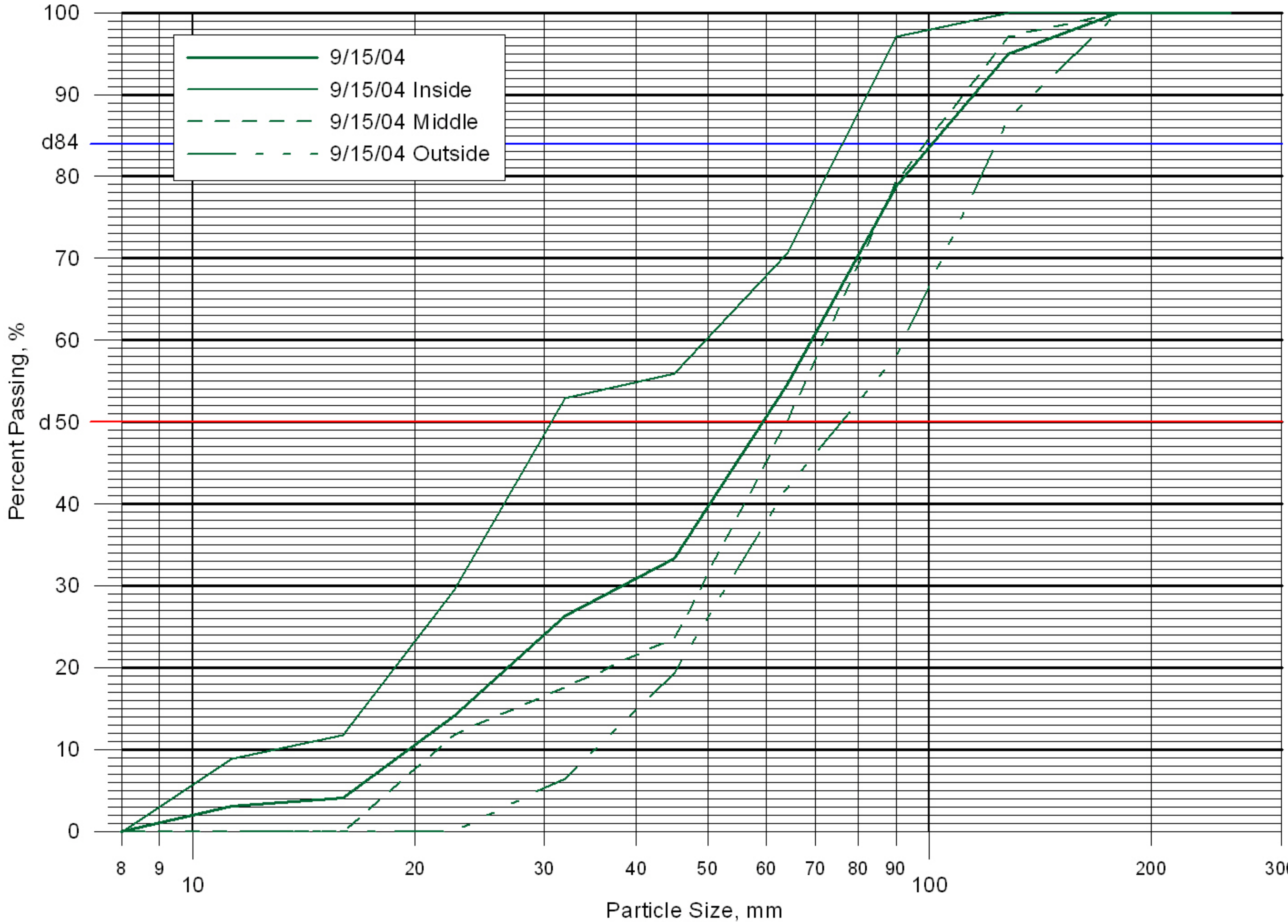


Figure 5.2.8. Pebble Count Results, Section 4c (Developing Point Bar)

Figure 5.2.8

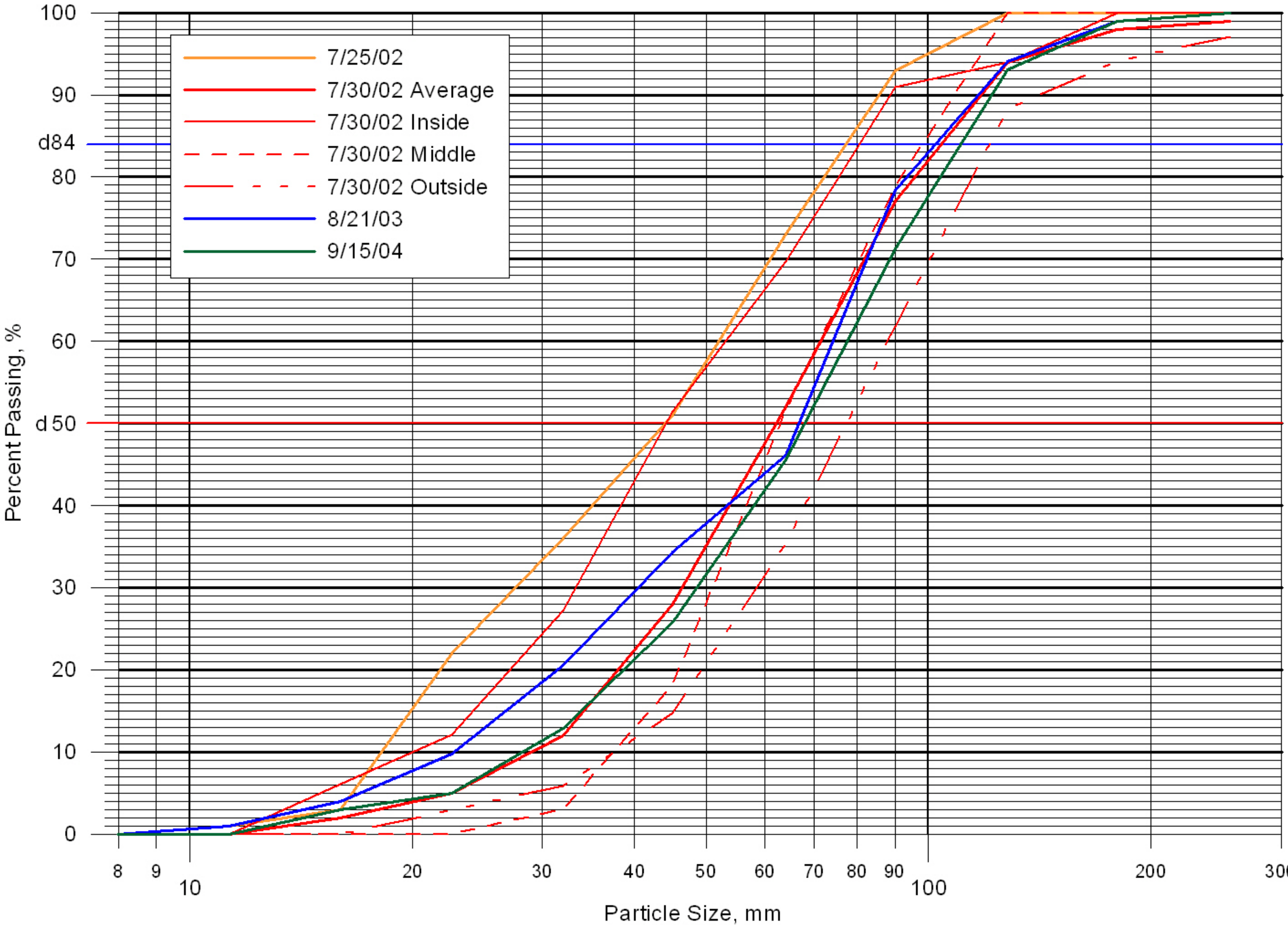


Figure 5.2.9. Pebble Count Results, Section 5 (Pool)

Figure 5.2.9

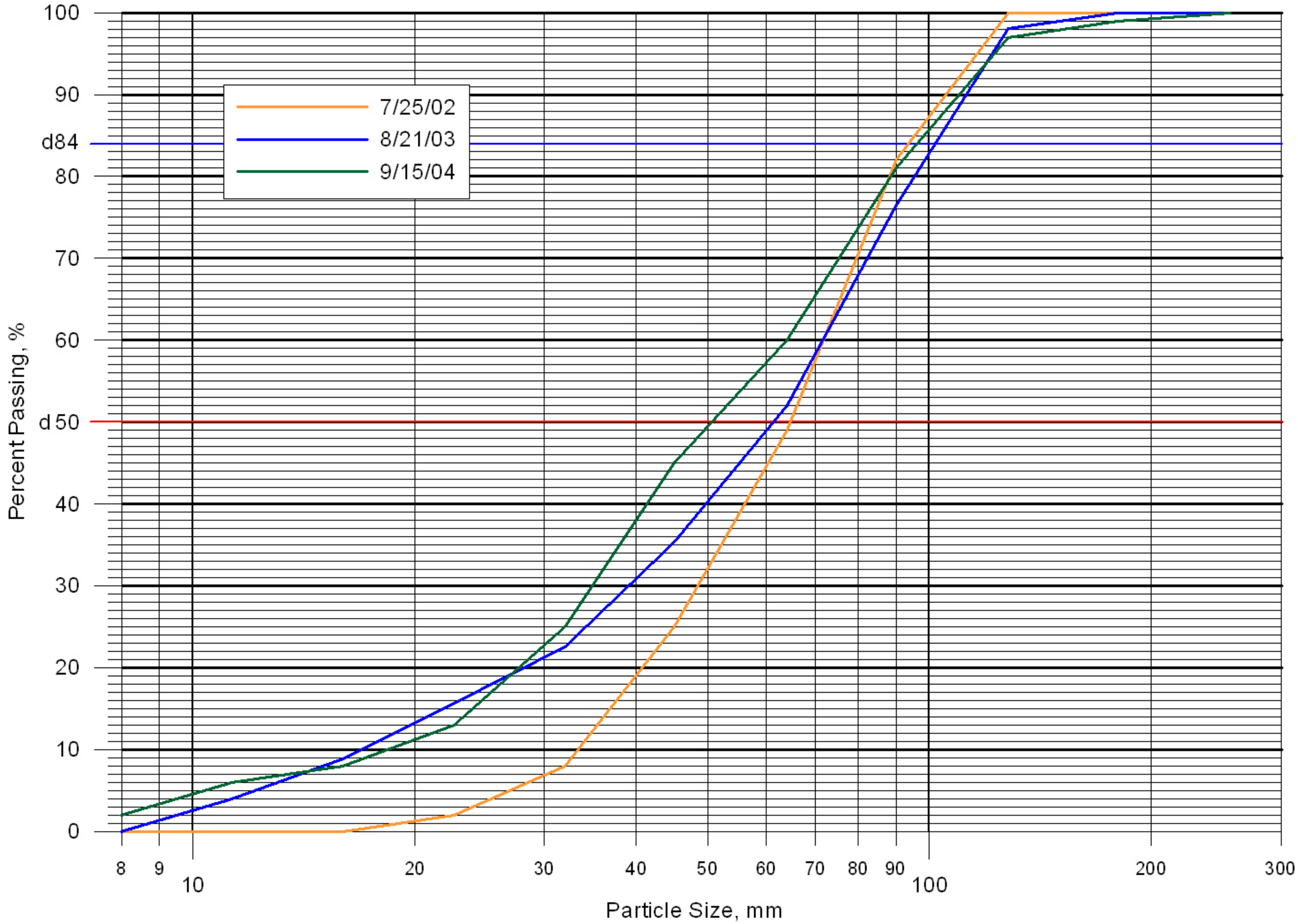


Figure 5.2.10. Pebble Count Results, Section 6 (Riffle)

Figure 5.2.10

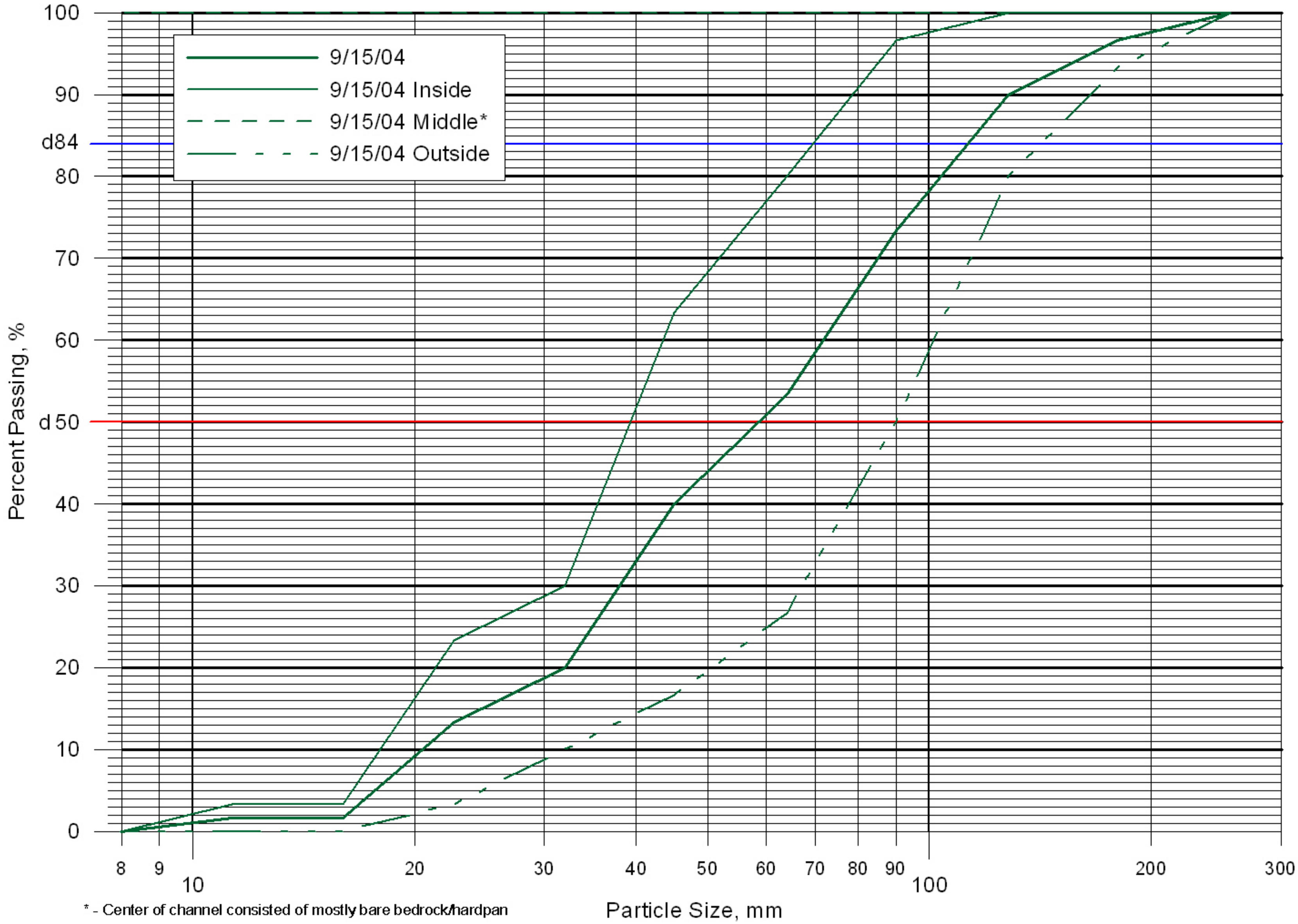
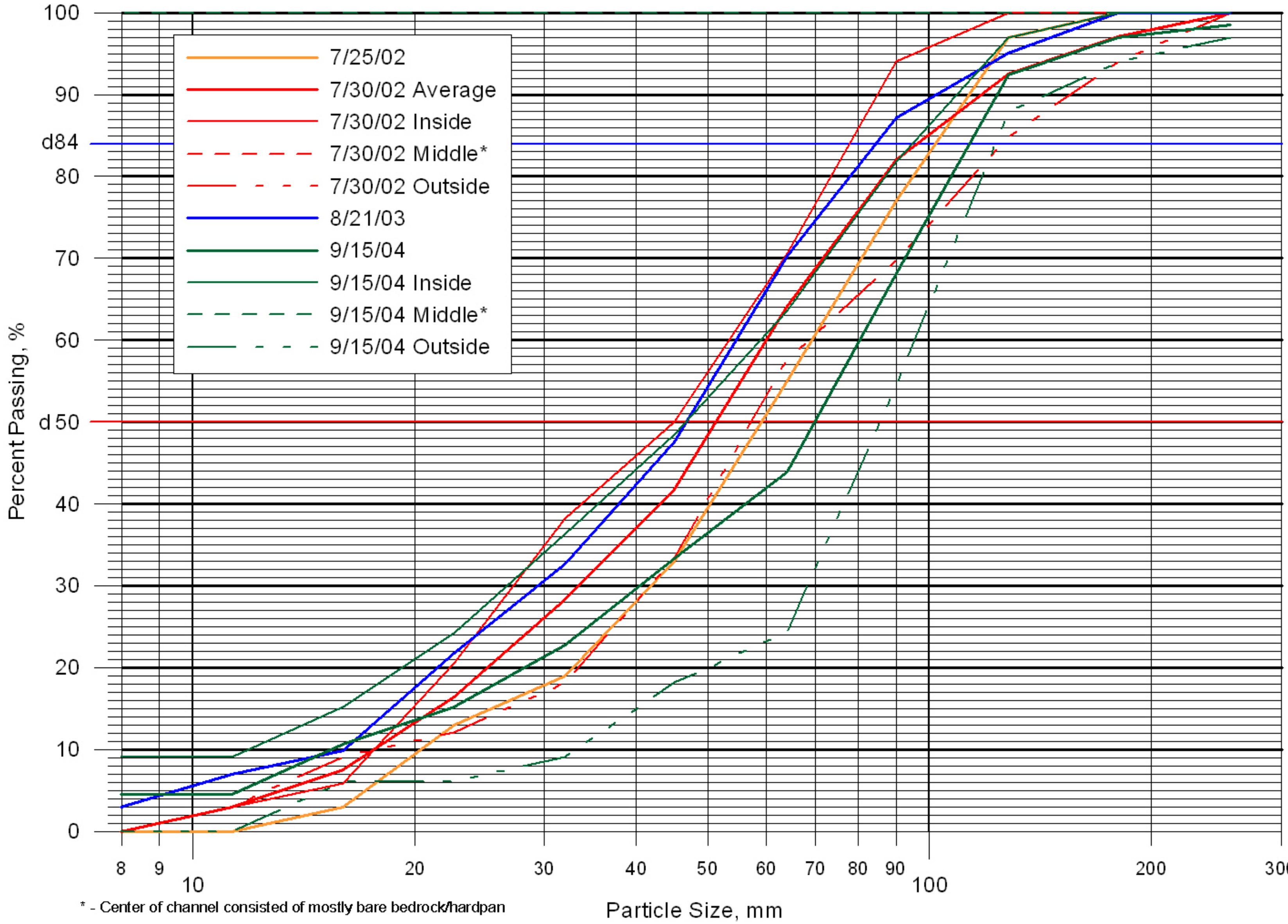


Figure 5.2.11. Pebble Count Results, Section 6b (Developing Point Bar)

Figure 5.2.11



* - Center of channel consisted of mostly bare bedrock/hardpan

Figure 5.2.12. Pebble Count Results, Section 7 (Pool)

Figure 5.2.12

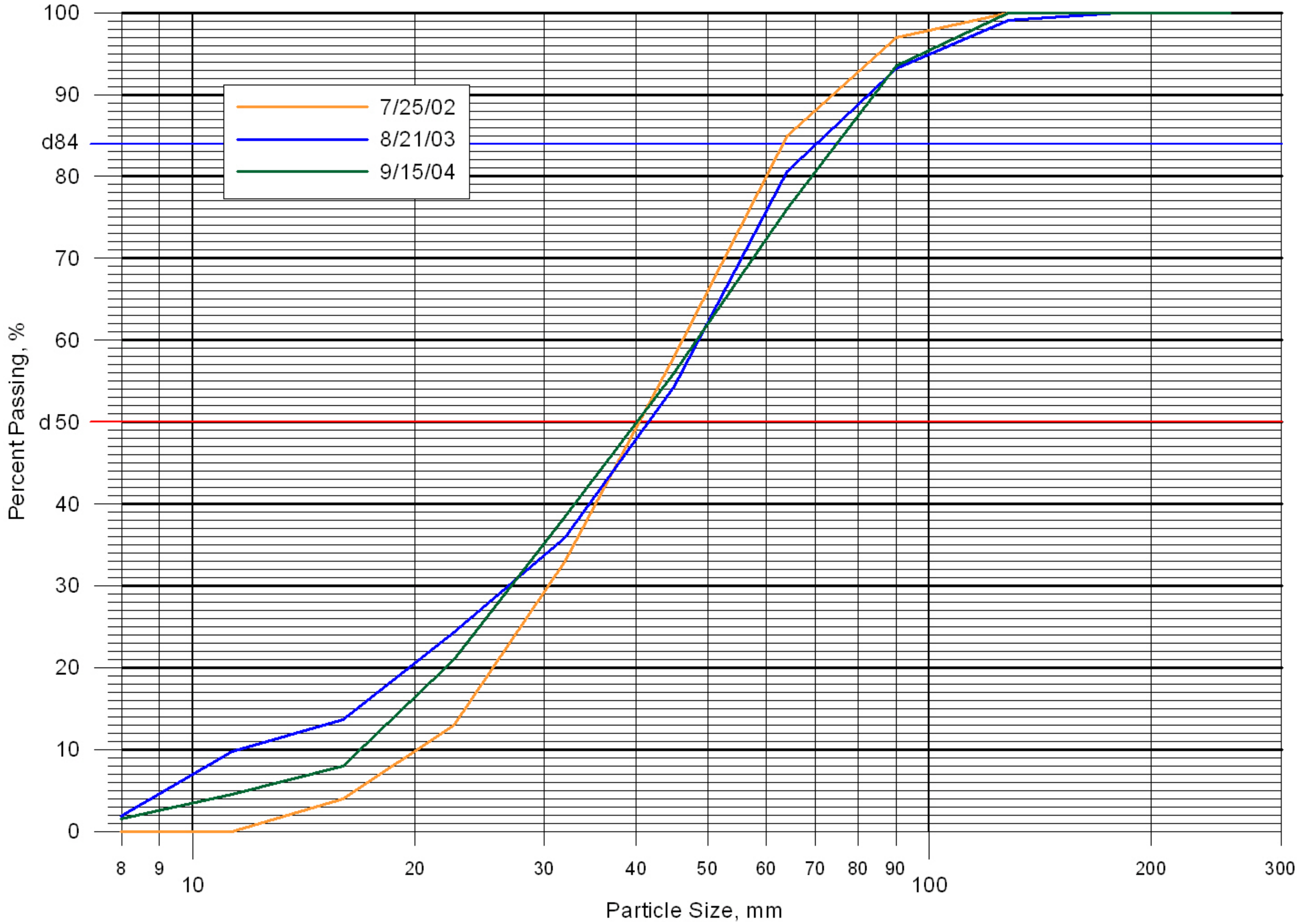


Figure 5.2.13. Pebble Count Results, Section 8 (Transition)

Figure 5.2.13

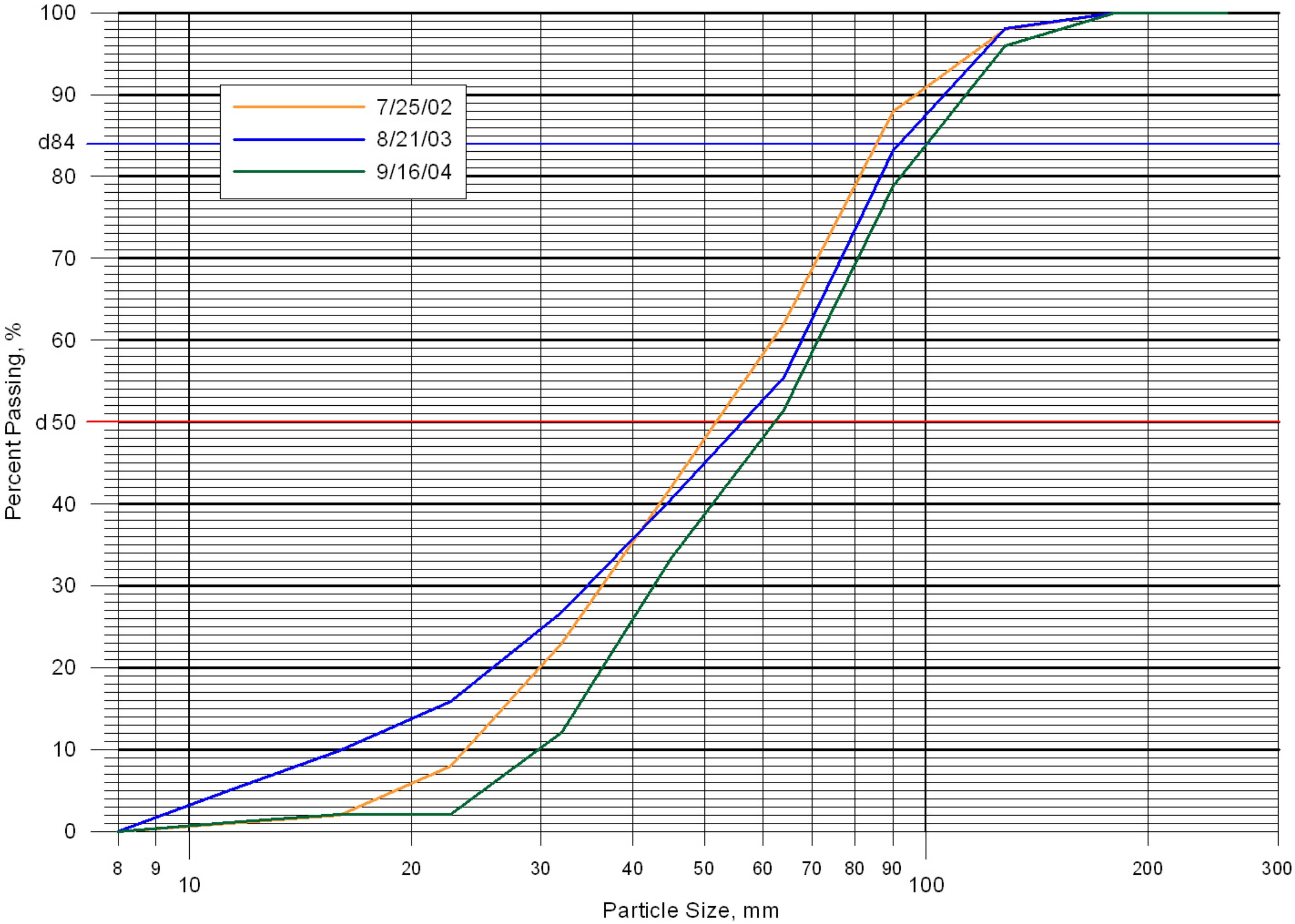


Figure 5.2.14. Pebble Count Results, Section 9 (Riffle)

Figure 5.2.14

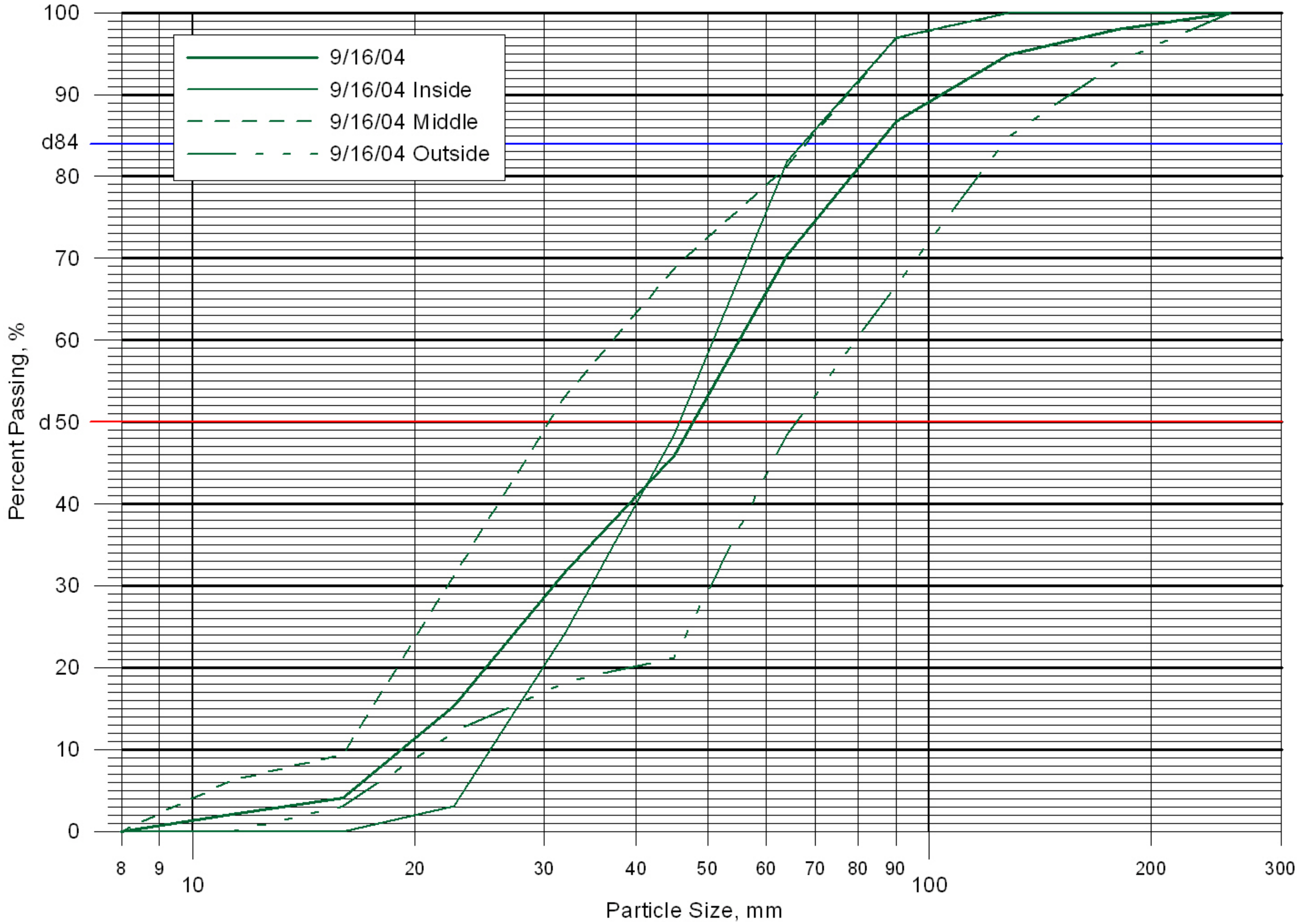


Figure 5.2.15. Pebble Count Results, Section 9b (Developing Point Bar)

Figure 5.2.15

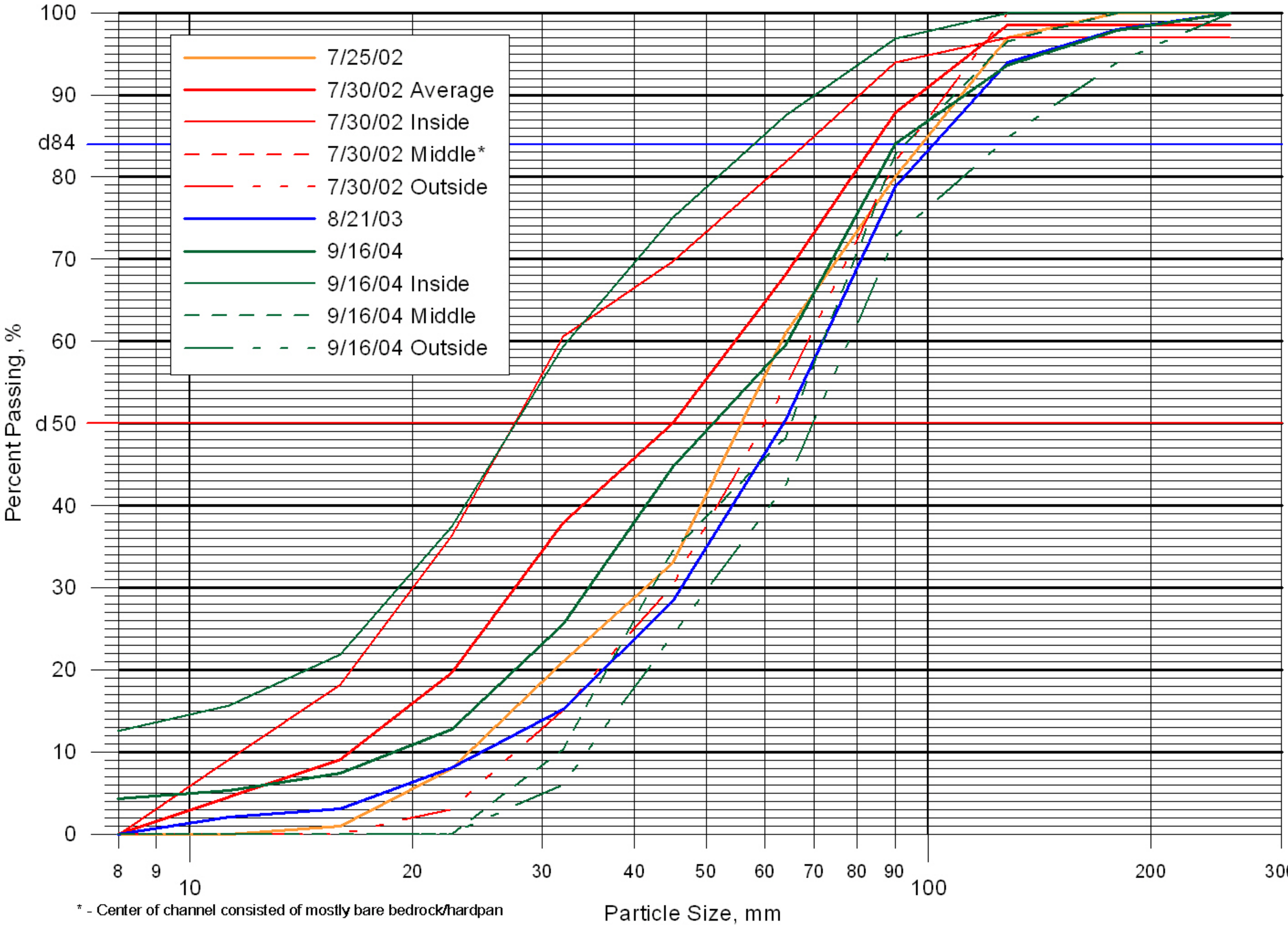


Figure 5.2.16. Pebble Count Results, Section 10 (Pool)

Figure 5.2.16

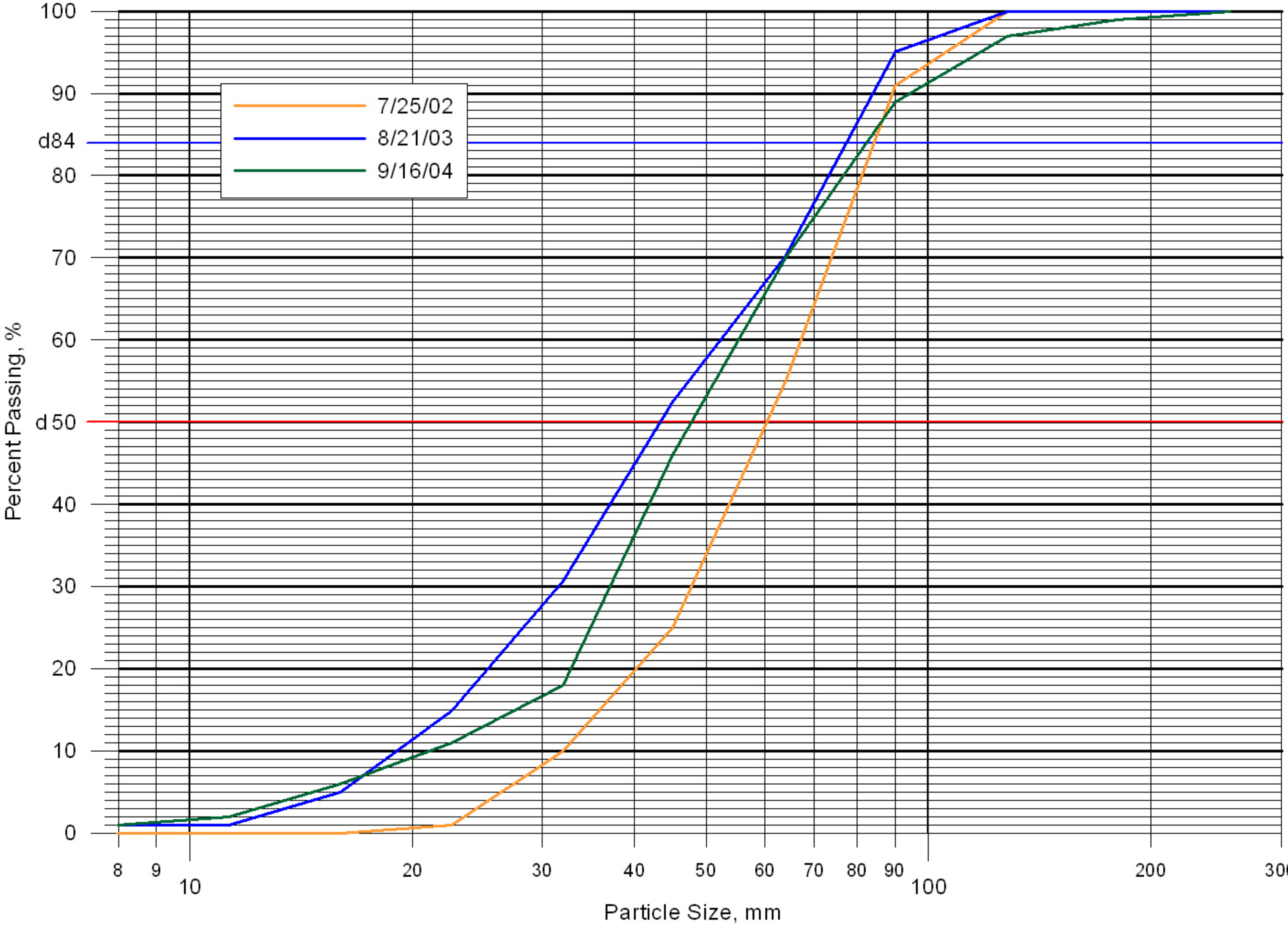


Figure 5.2.17. Pebble Count Results, Section 11 (Transition)

Figure 5.2.17

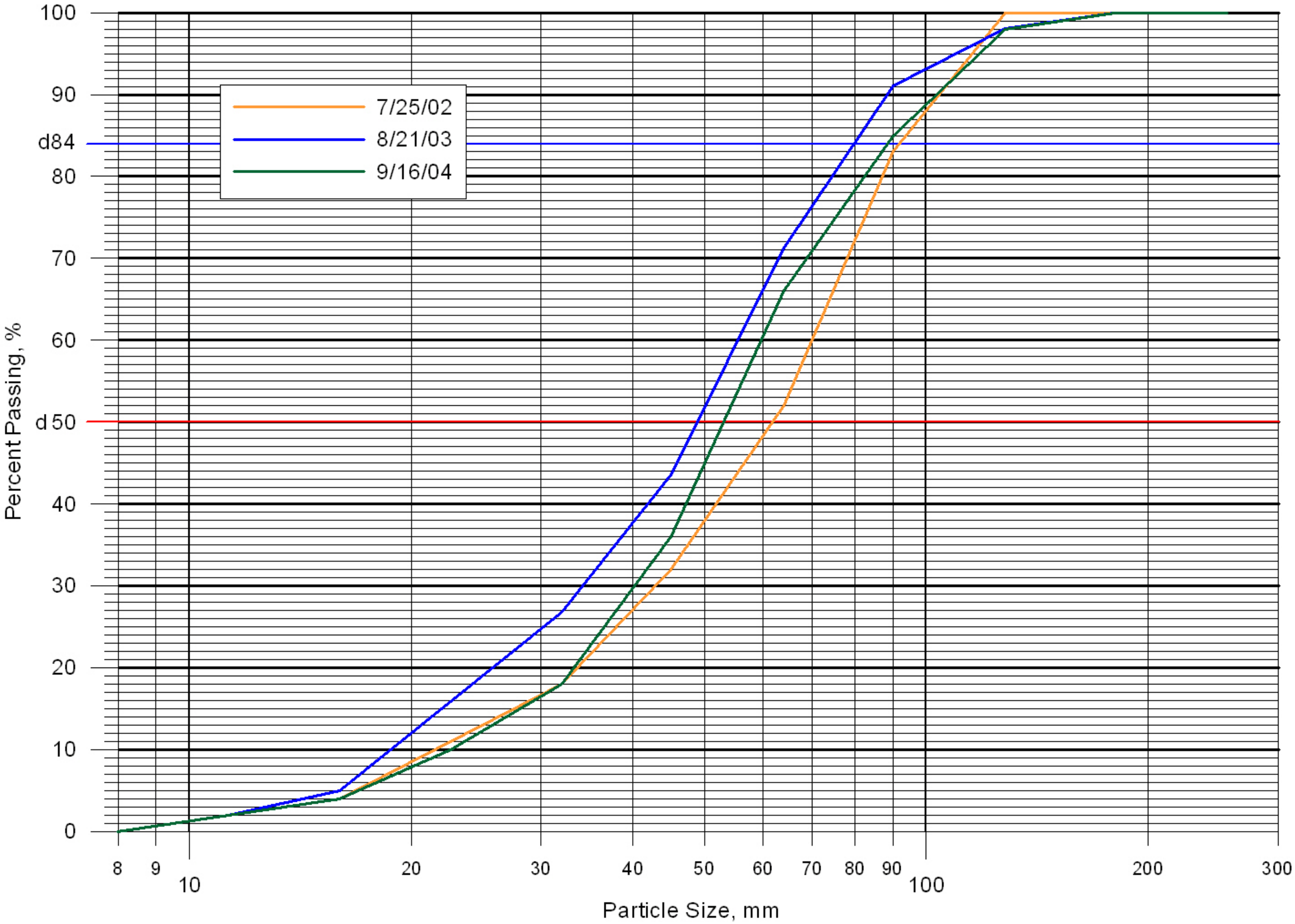


Figure 5.2.18. Pebble Count Results, Section 12 (Riffle)

Figure 5.2.18

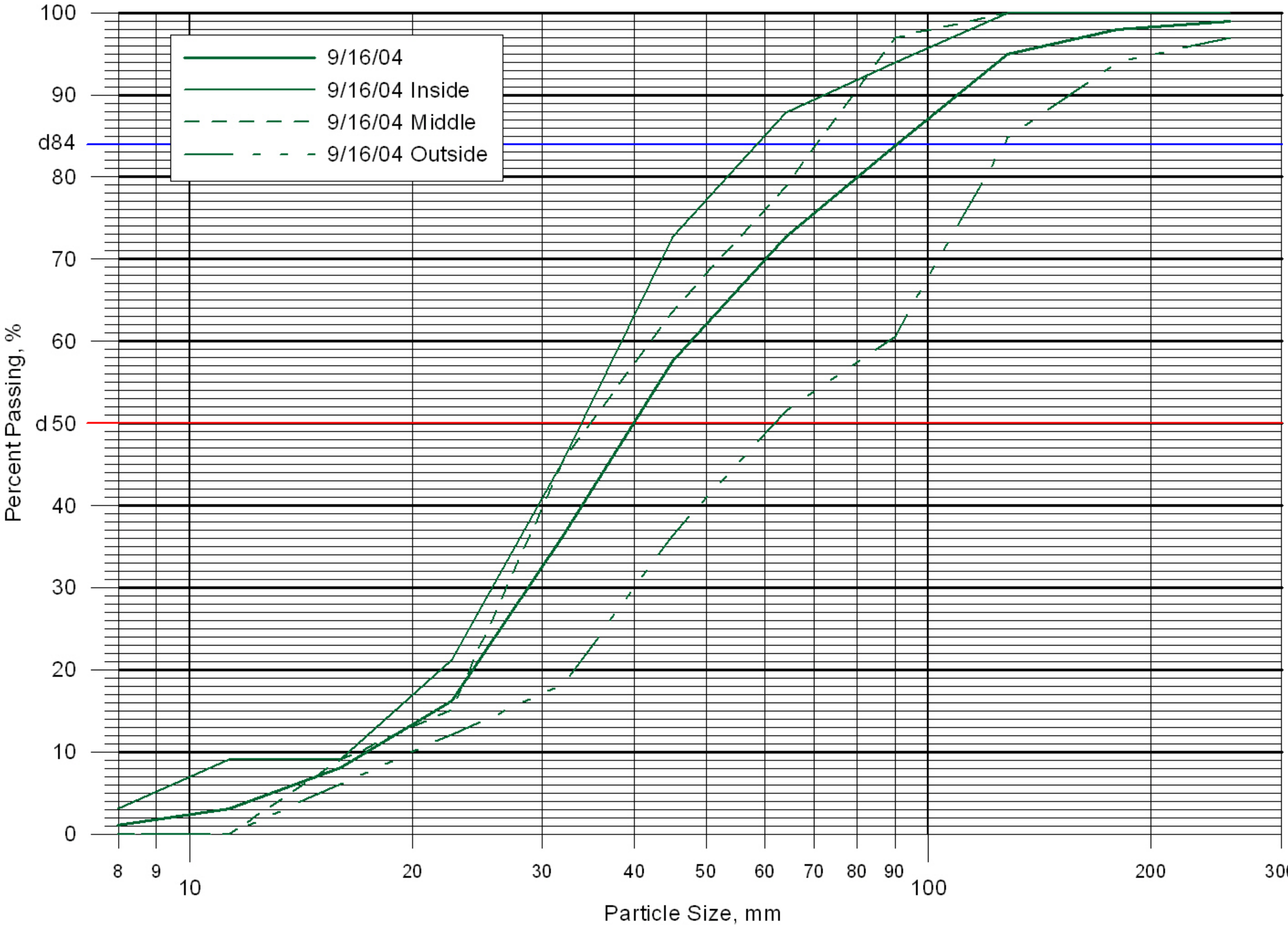


Figure 5.2.19. Pebble Count Results, Section 12b (Developing Point Bar)

Figure 5.2.19

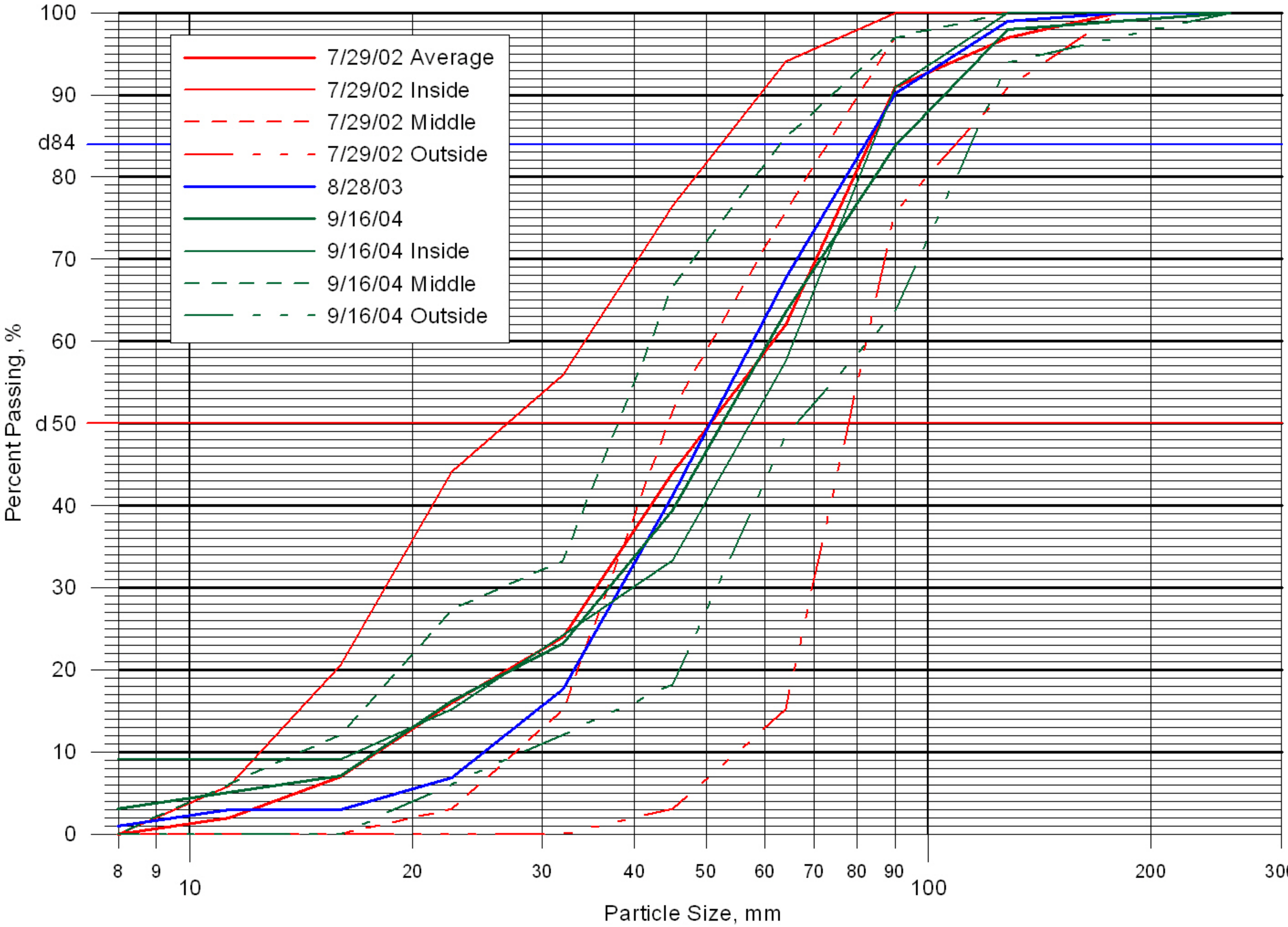


Figure 5.2.20. Pebble Count Results, Section 13 (Pool)

Figure 5.2.20

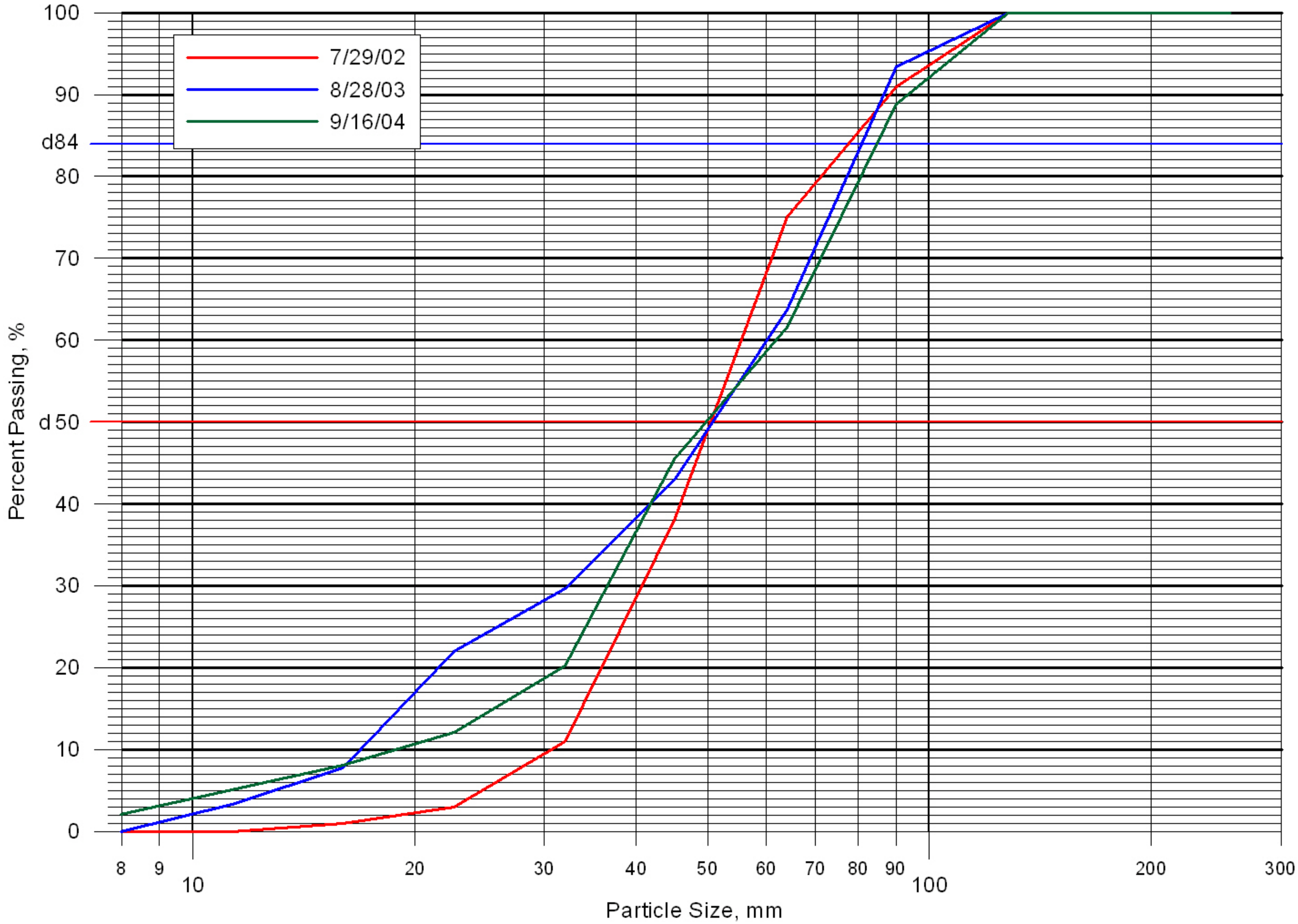


Figure 5.2.21. Pebble Count Results, Section 14 (Transition)

Figure 5.2.21

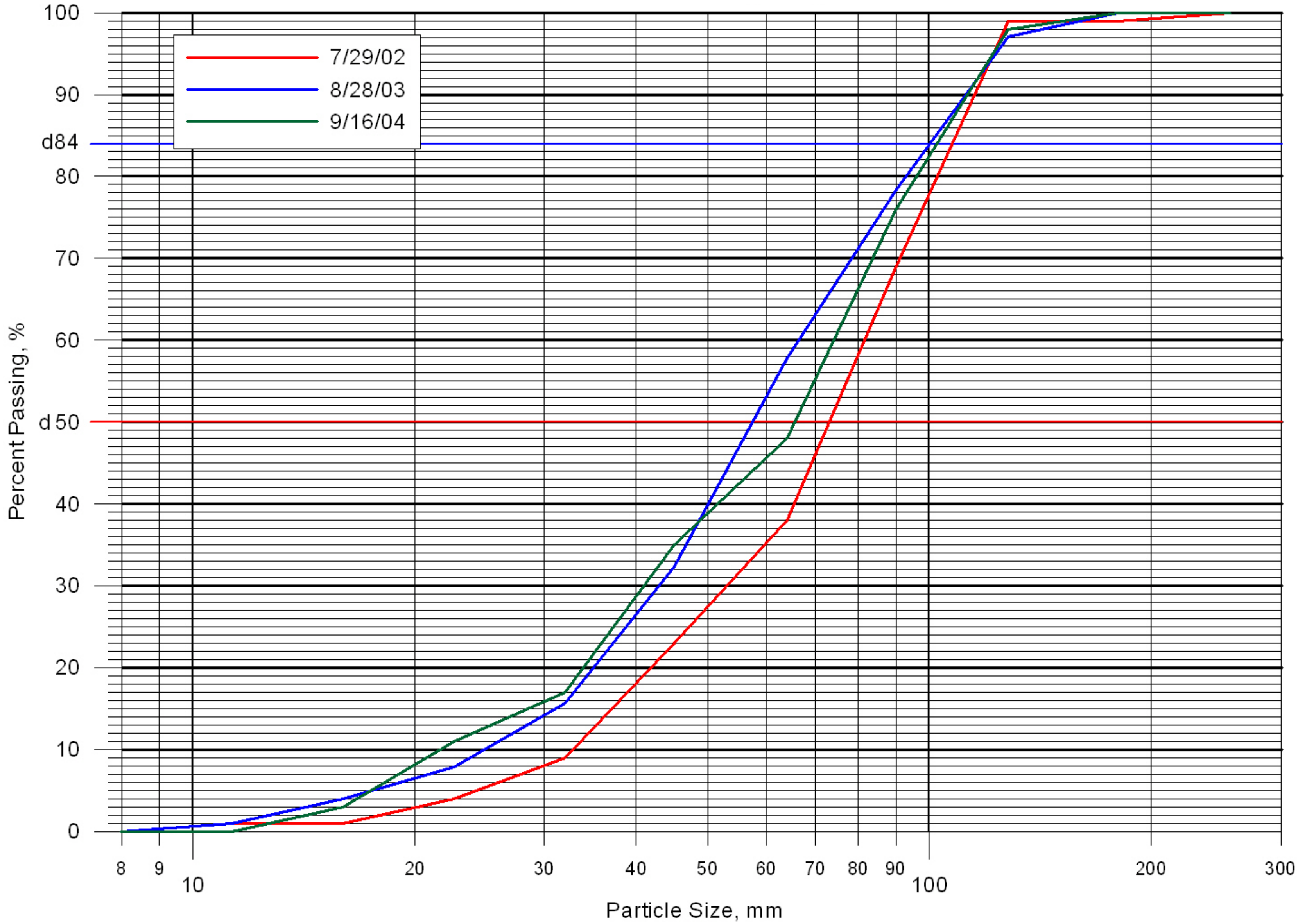
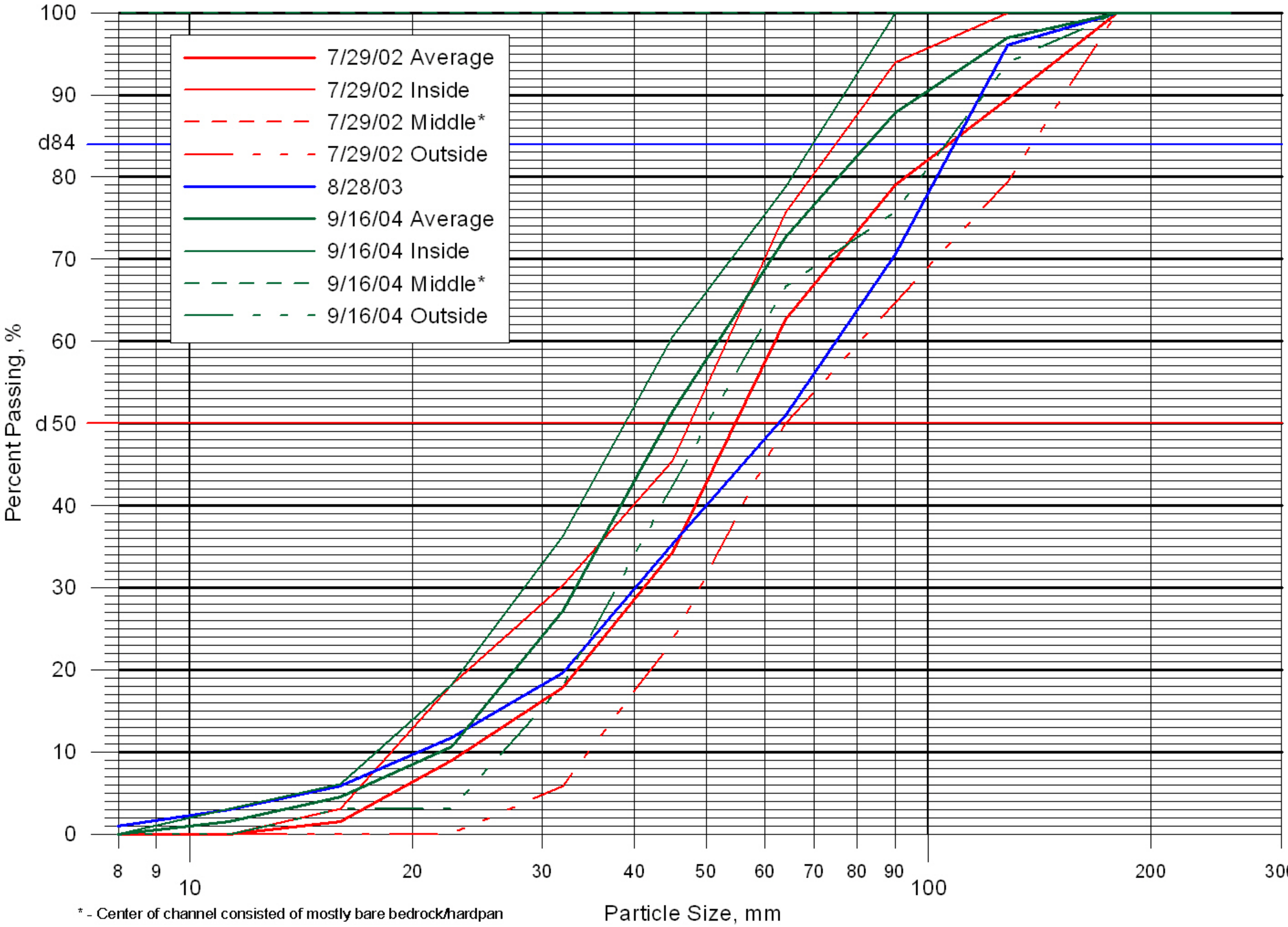


Figure 5.2.22. Pebble Count Results, Section 15 (Riffle)

Figure 5.2.22



* - Center of channel consisted of mostly bare bedrock/hardpan

Figure 5.2.23. Pebble Count Results, Section 16 (Pool)

Figure 5.2.23

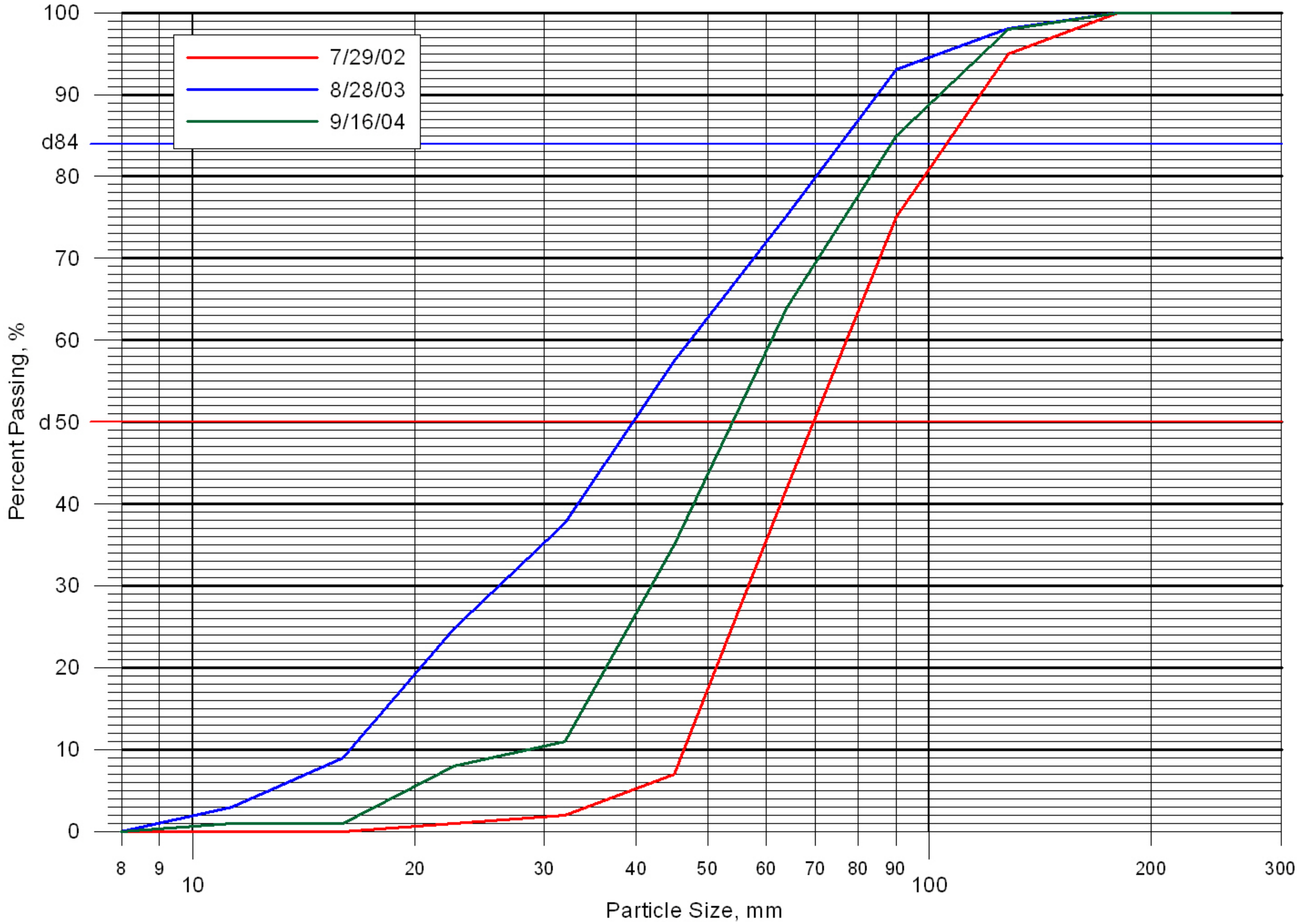


Figure 5.2.24. Pebble Count Results, Section 17 (Riffle)

Figure 5.2.24

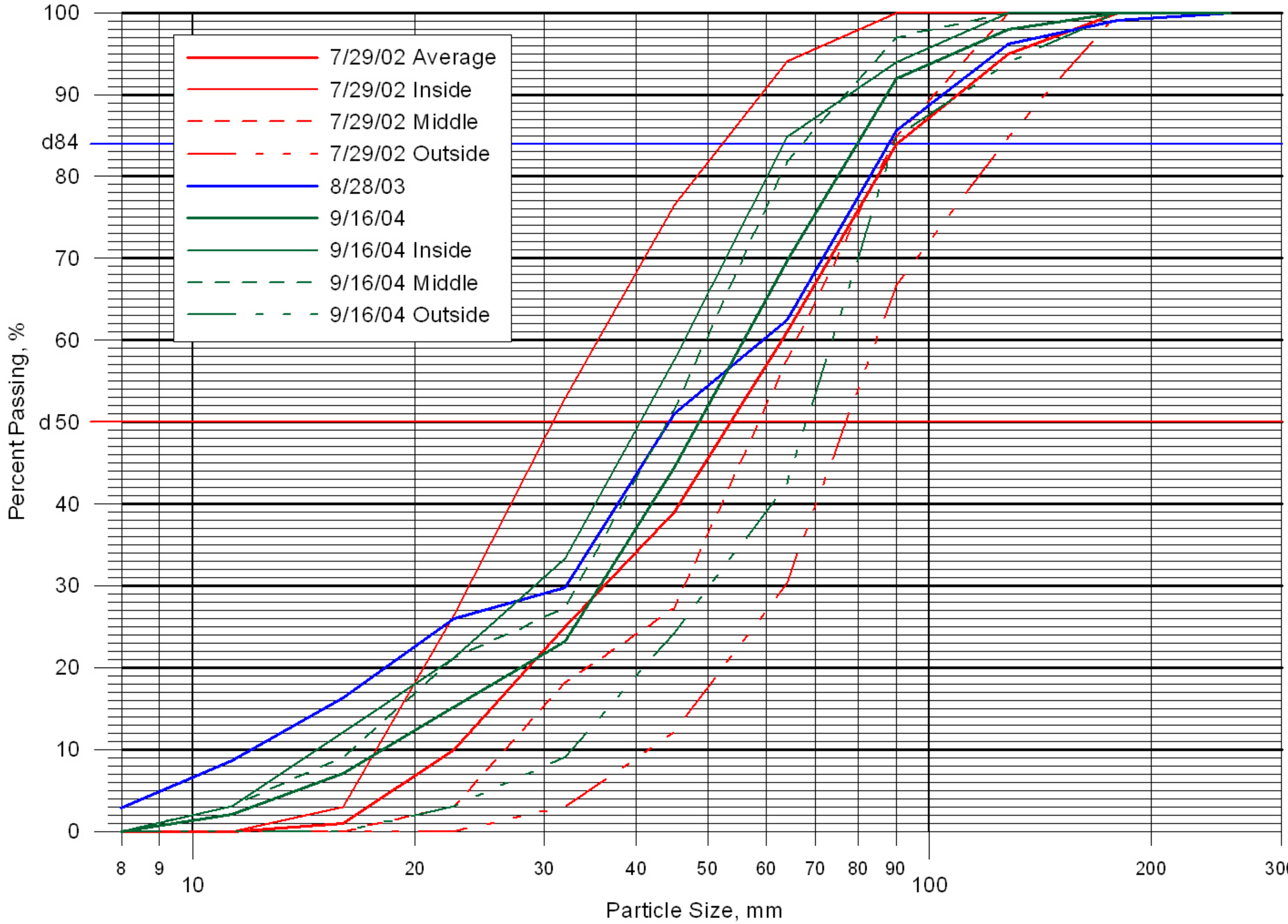


Figure 5.2.25. Pebble Count Results, Section 18 (Pool)

Figure 5.2.25

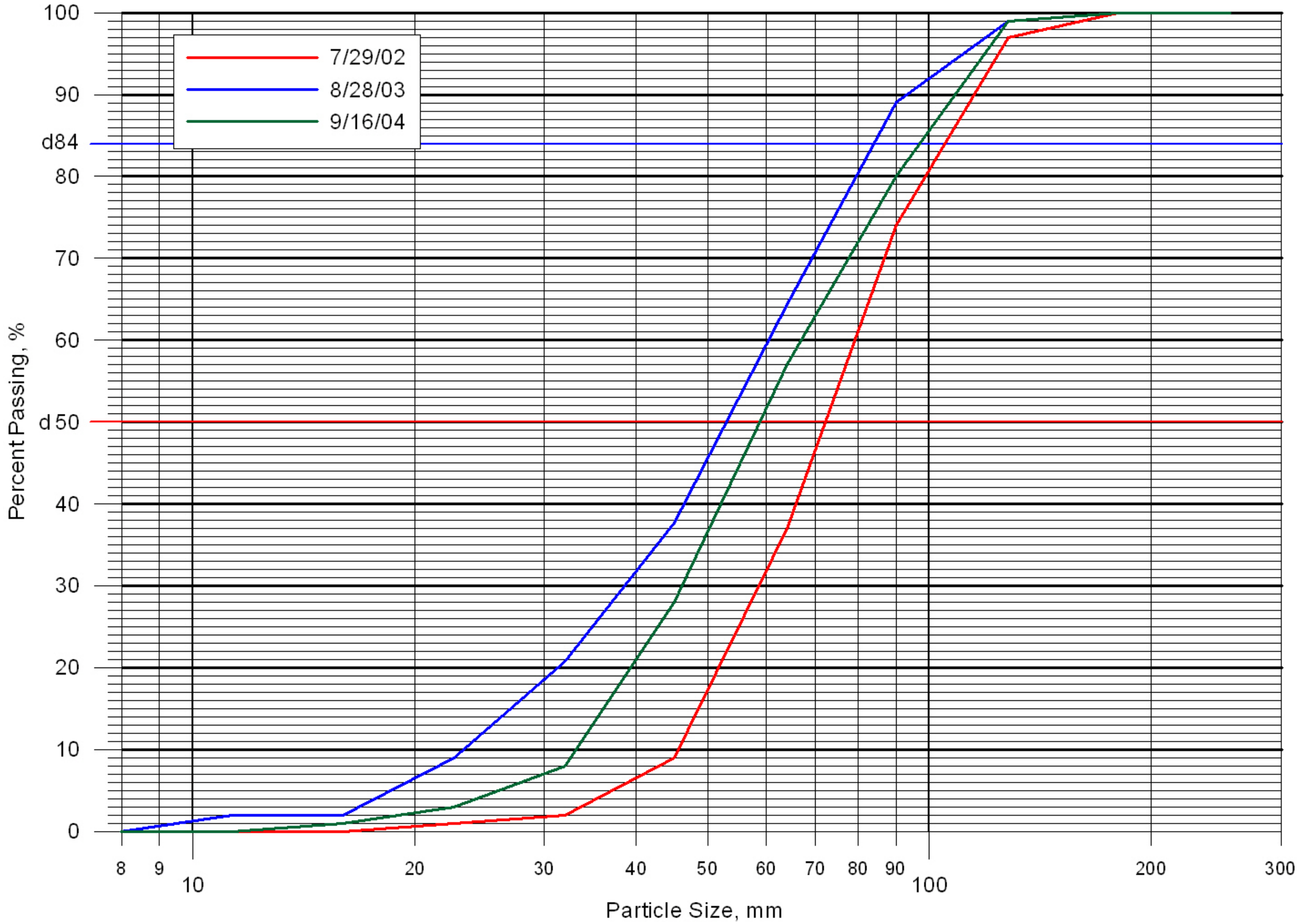


Figure 5.2.26. Pebble Count Results, Section 19 (Riffle)

Figure 5.2.26

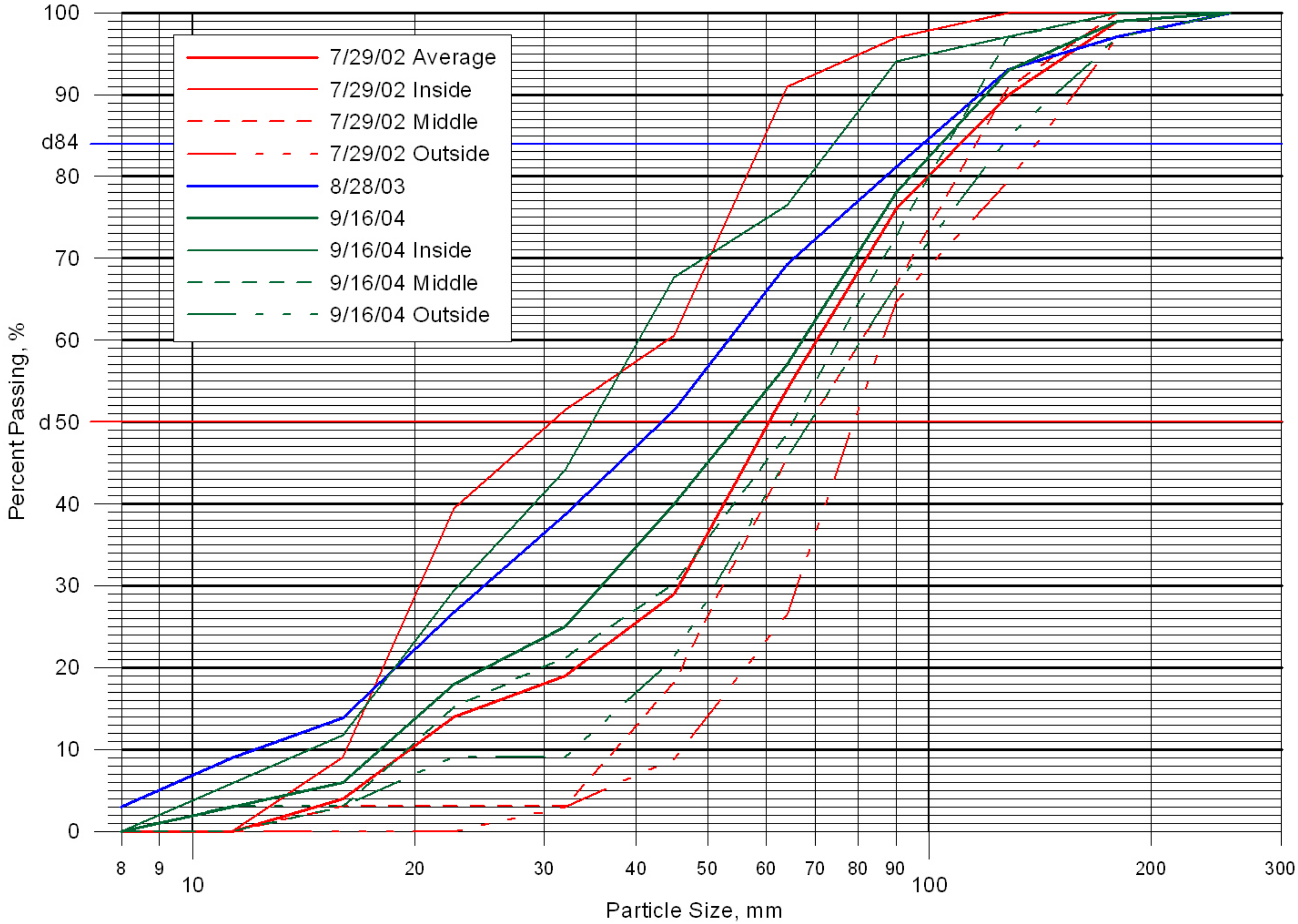


Figure 5.2.27. Pebble Count Results, Section 20 (Pool)

Figure 5.2.27

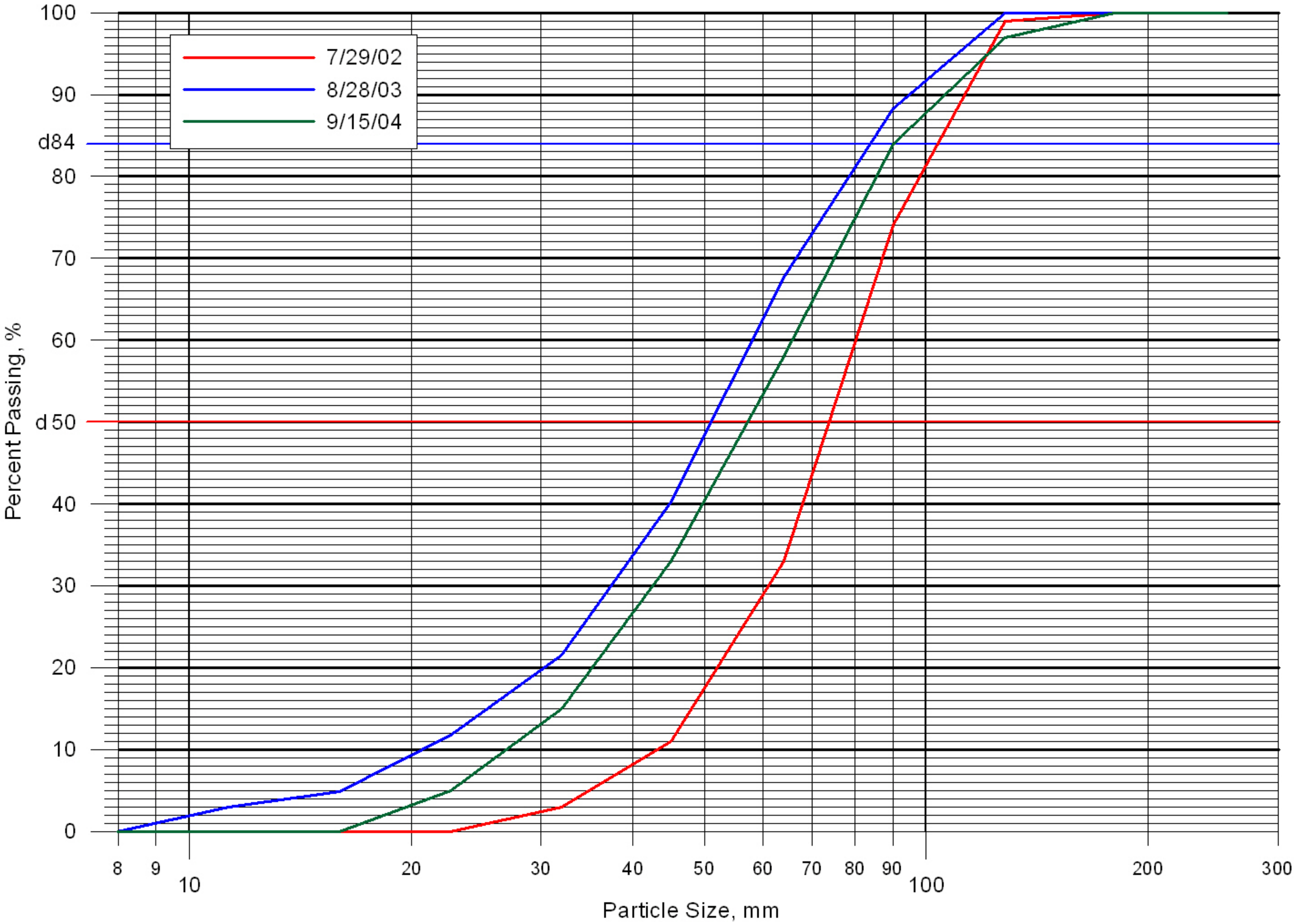


Figure 5.2.28. Pebble Count Results, Section 21 (Riffle)

Figure 5.2.28

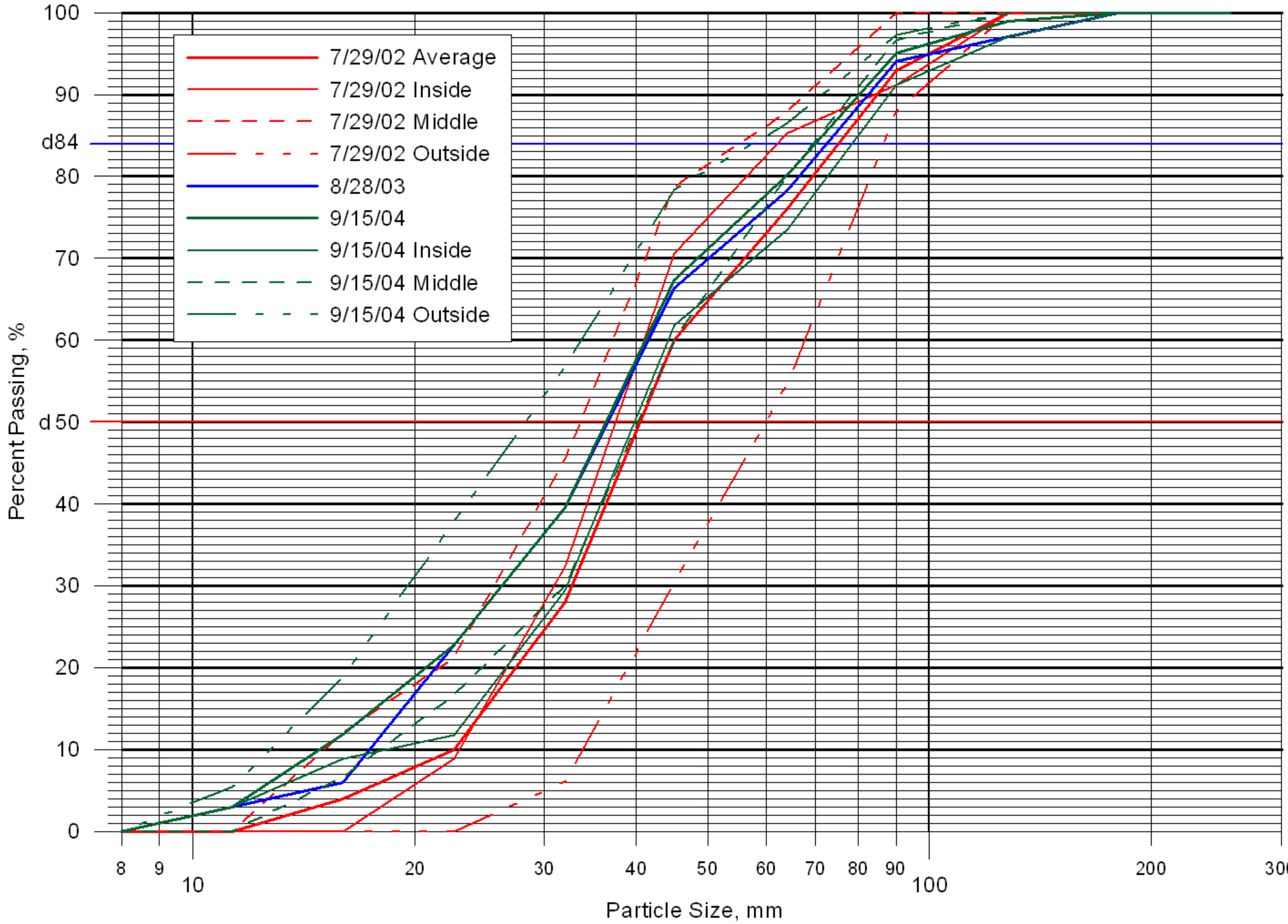


Figure 5.2.29. Pebble Count Results, Section 22 (Pool)

Figure 5.2.29

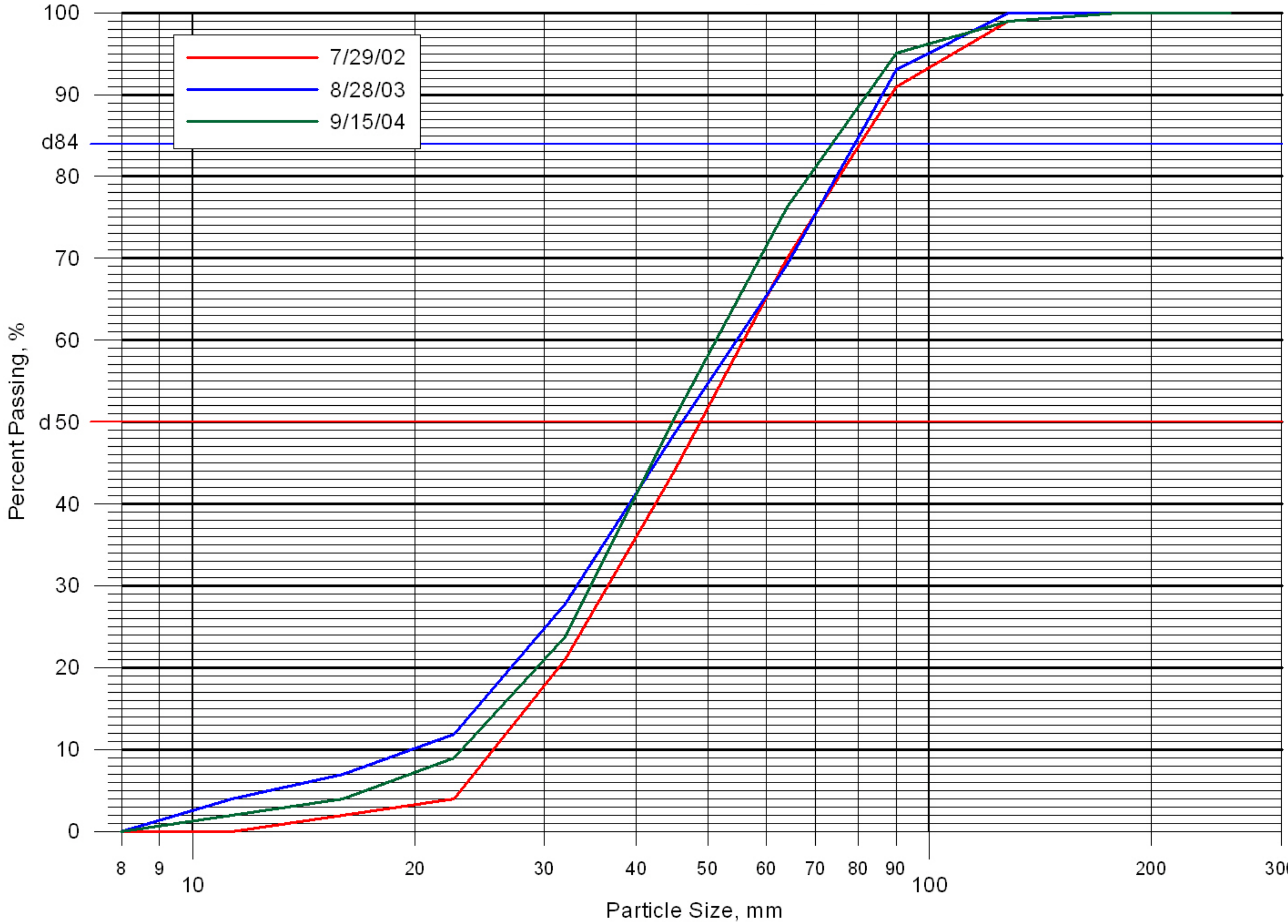


Figure 5.2.30. Pebble Count Results, Section 23 (Riffle)

Figure 5.2.30

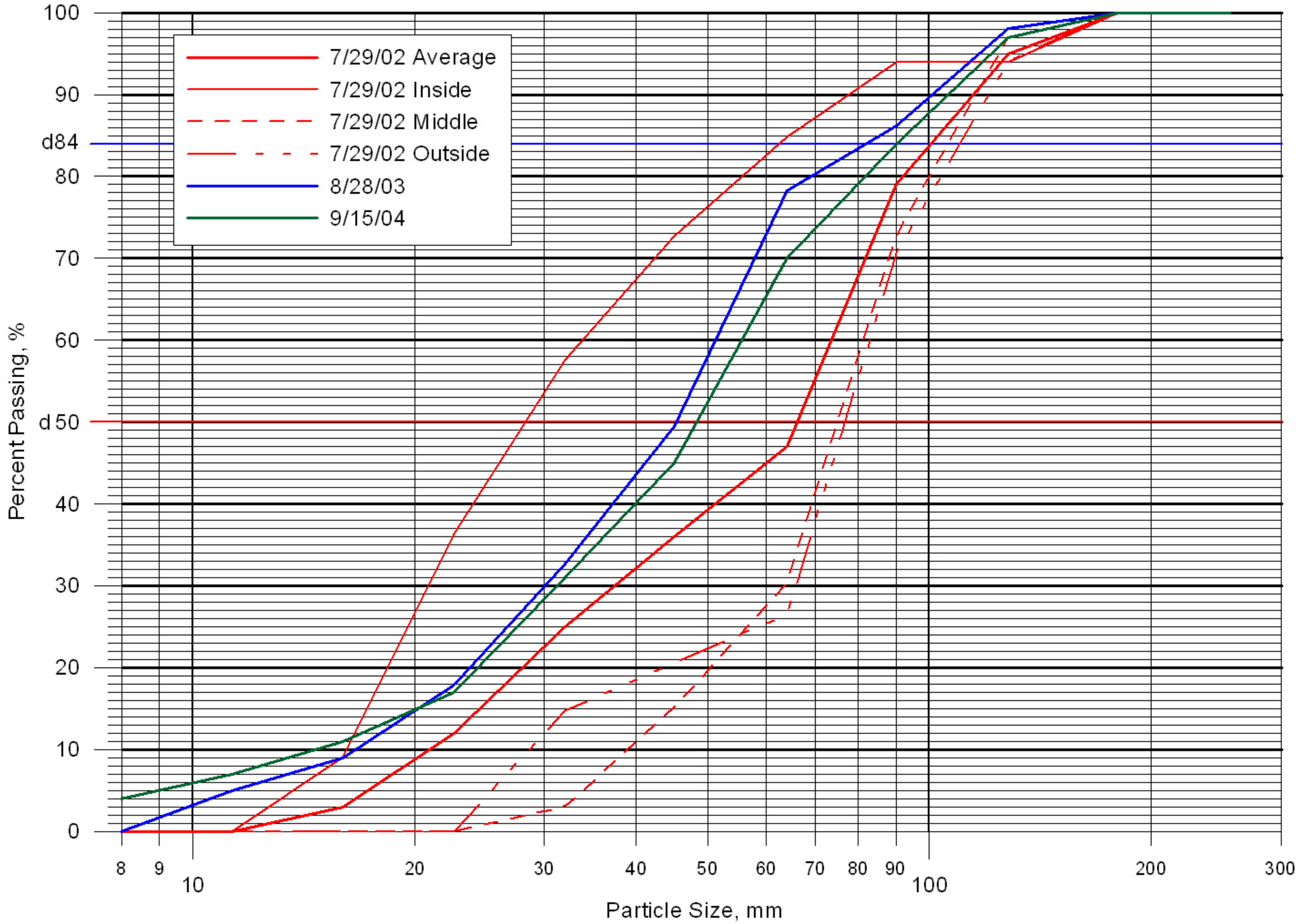


Figure 5.2.31. Pebble Count Results, Section 24 (Pool)

Figure 5.2.31

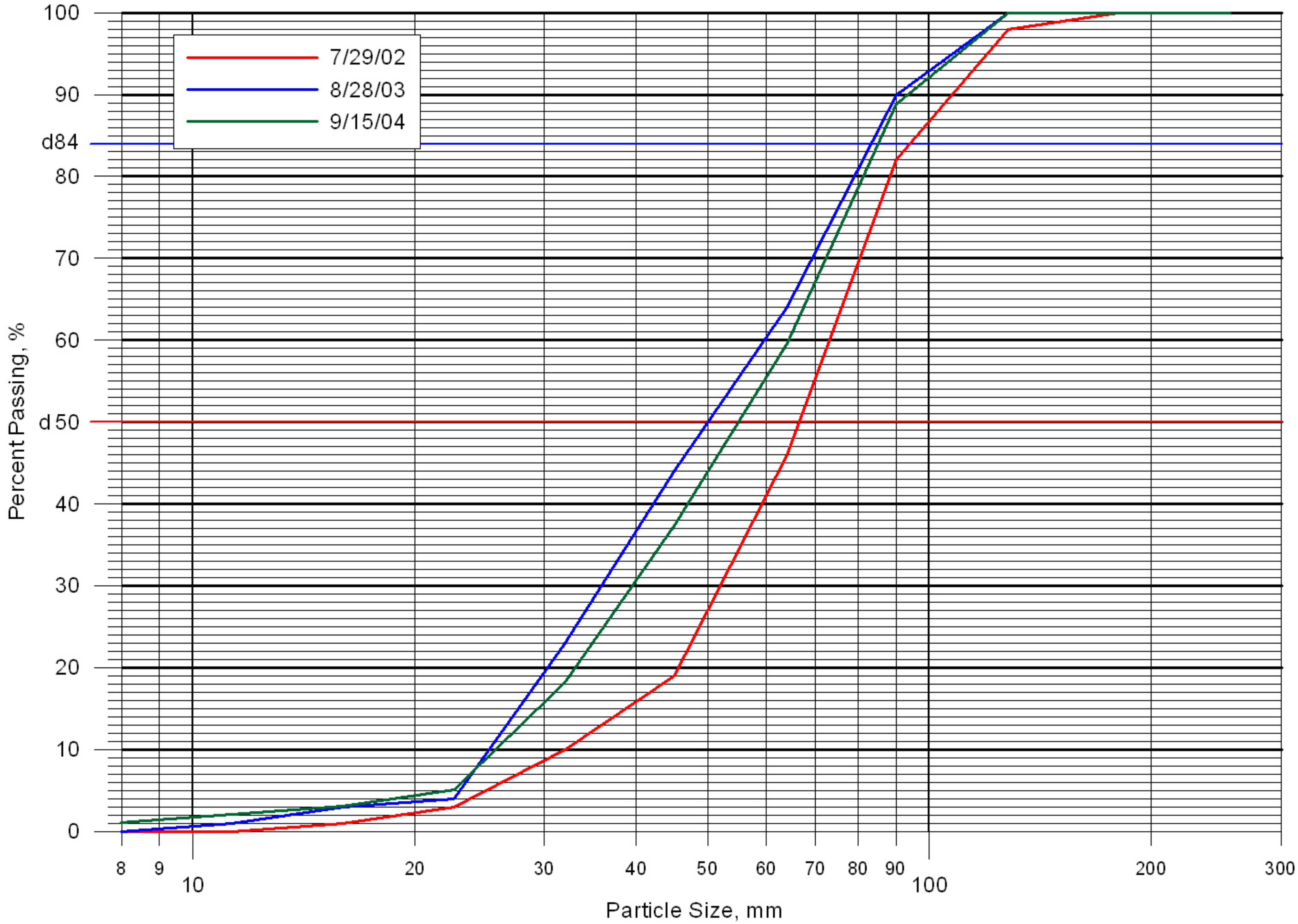


Figure 5.2.32. Pebble Count Results, Section 25 (Riffle)

Figure 5.2.32

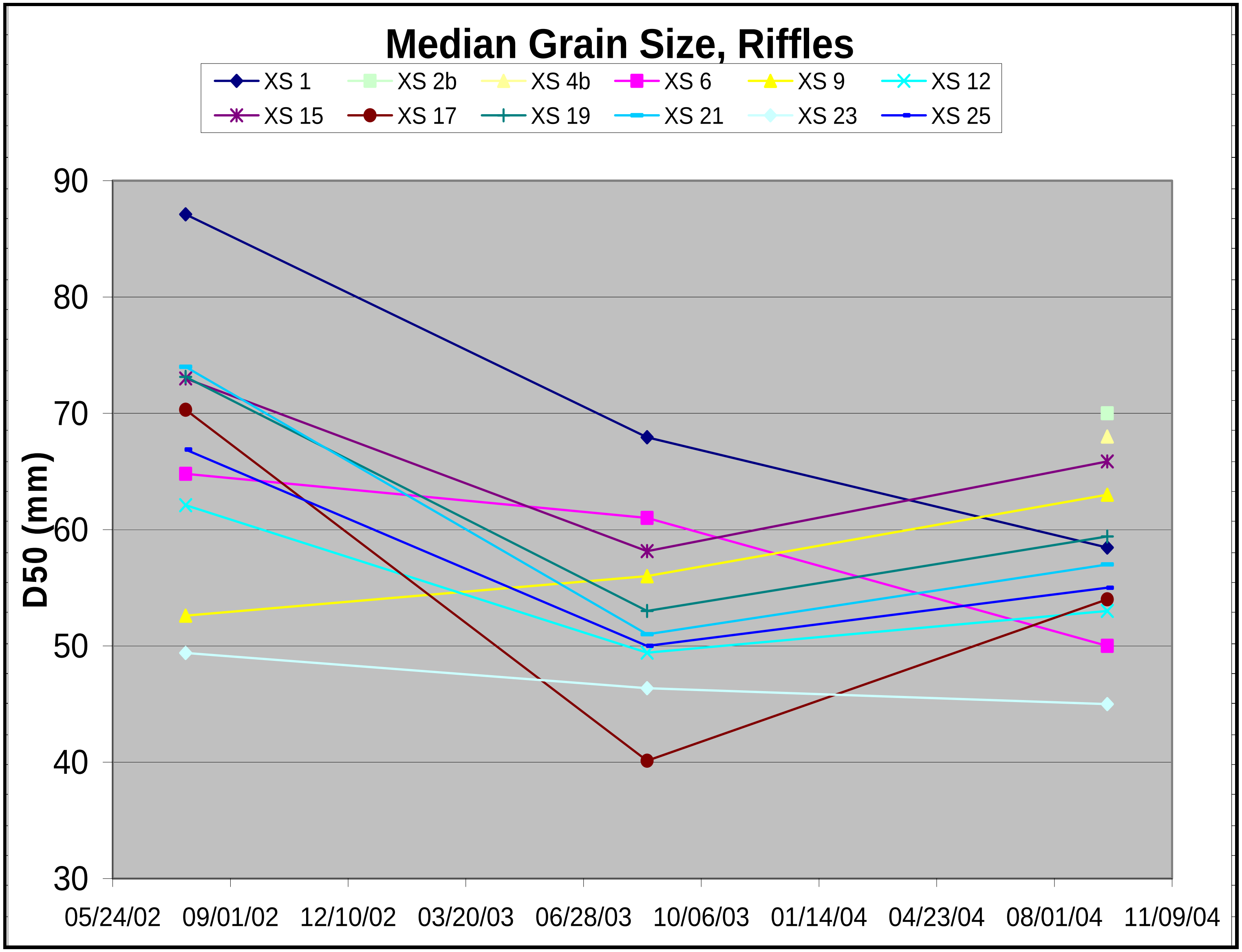


Figure 5.2.33. Pebble Count Results, Riffle Section Median Grain Sizes

Figure 5.2.33

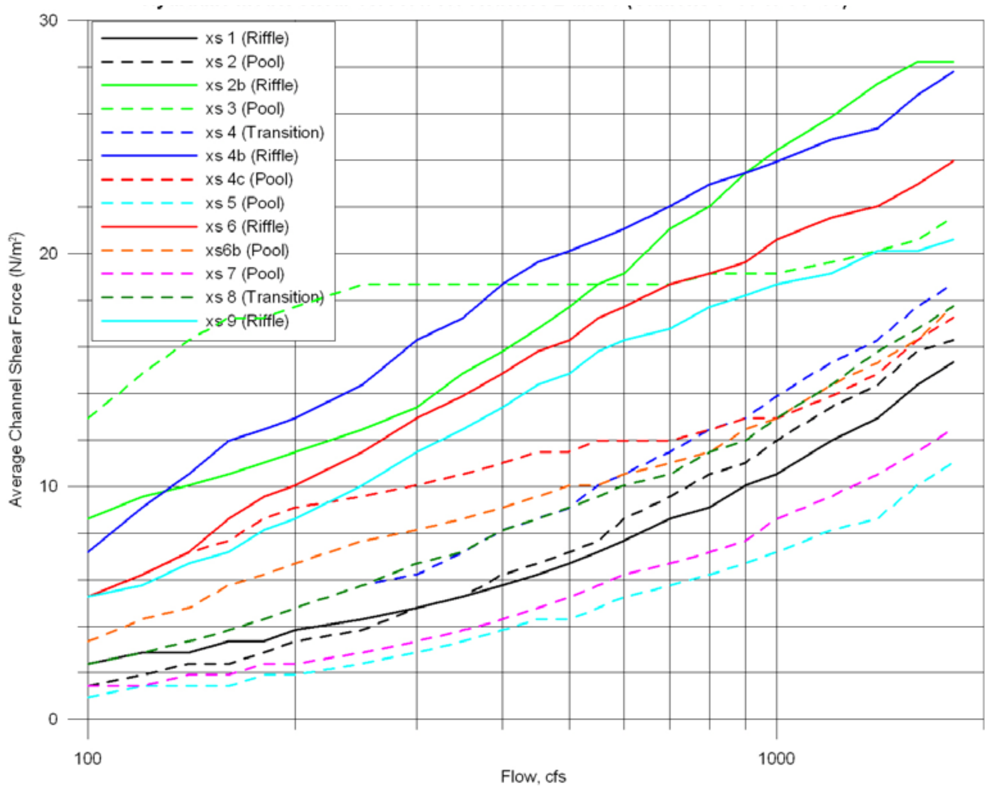


Figure 5.2.34a. HEC-RAS Average Channel Shear vs. Flow, Reaches 2 and 3

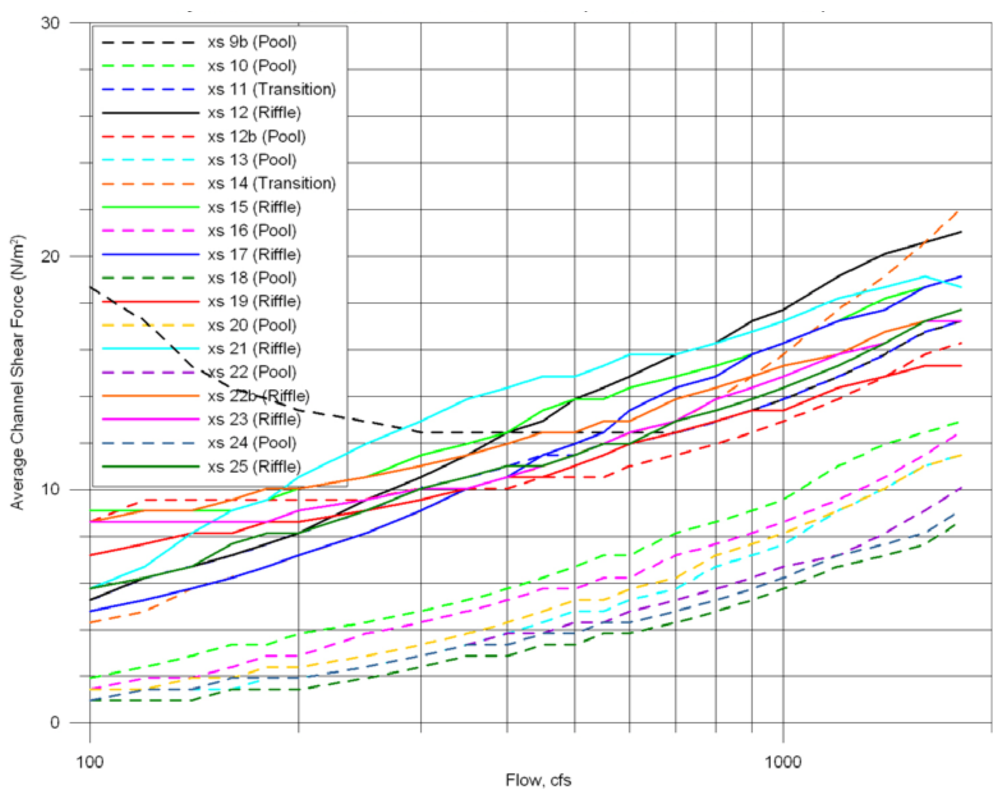


Figure 5.2.34b. HEC-RAS Average Channel Shear vs. Flow, Reach 4

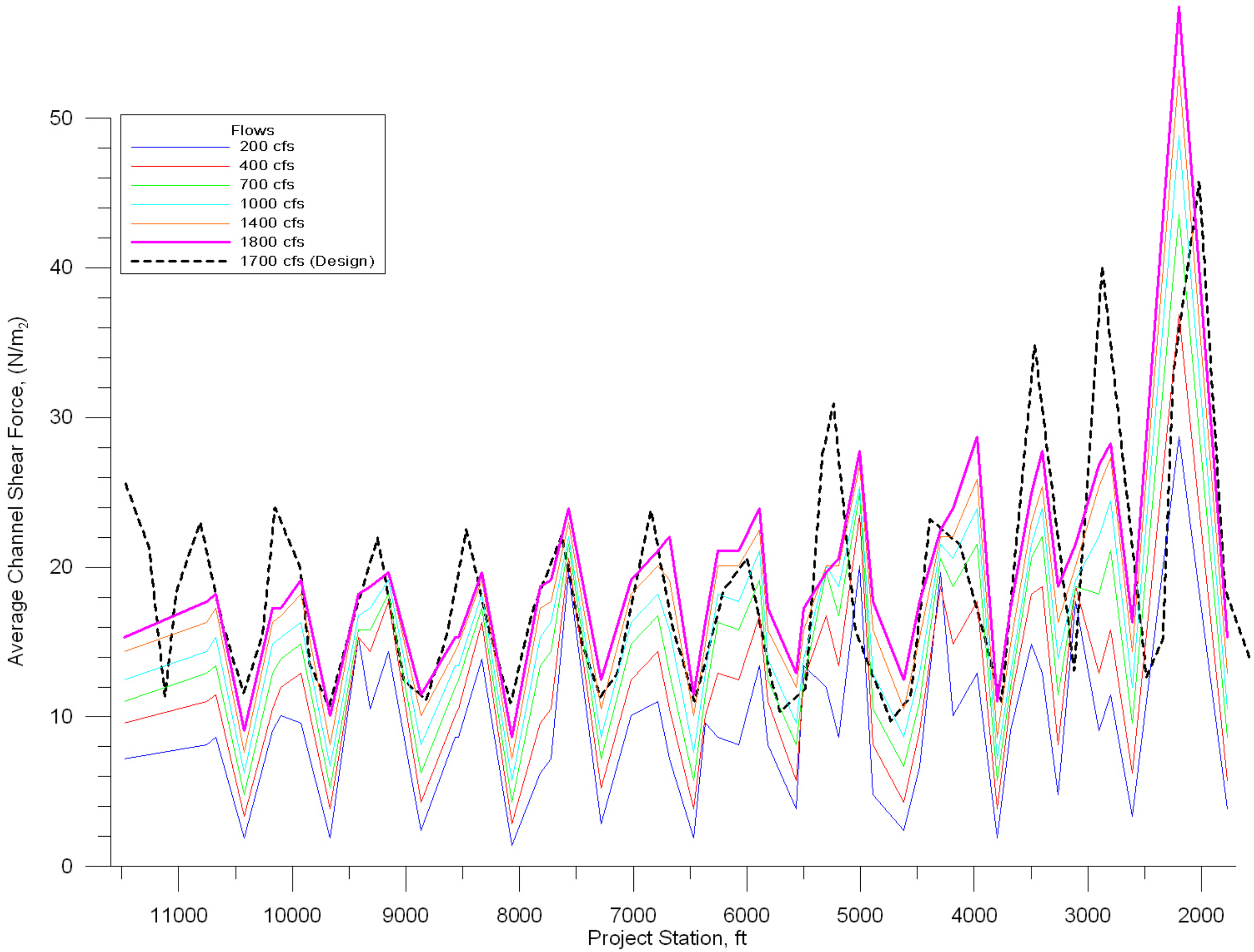


Figure 5.2.35. HEC-RAS Average Channel Shear vs. Station

Figure 5.2.35

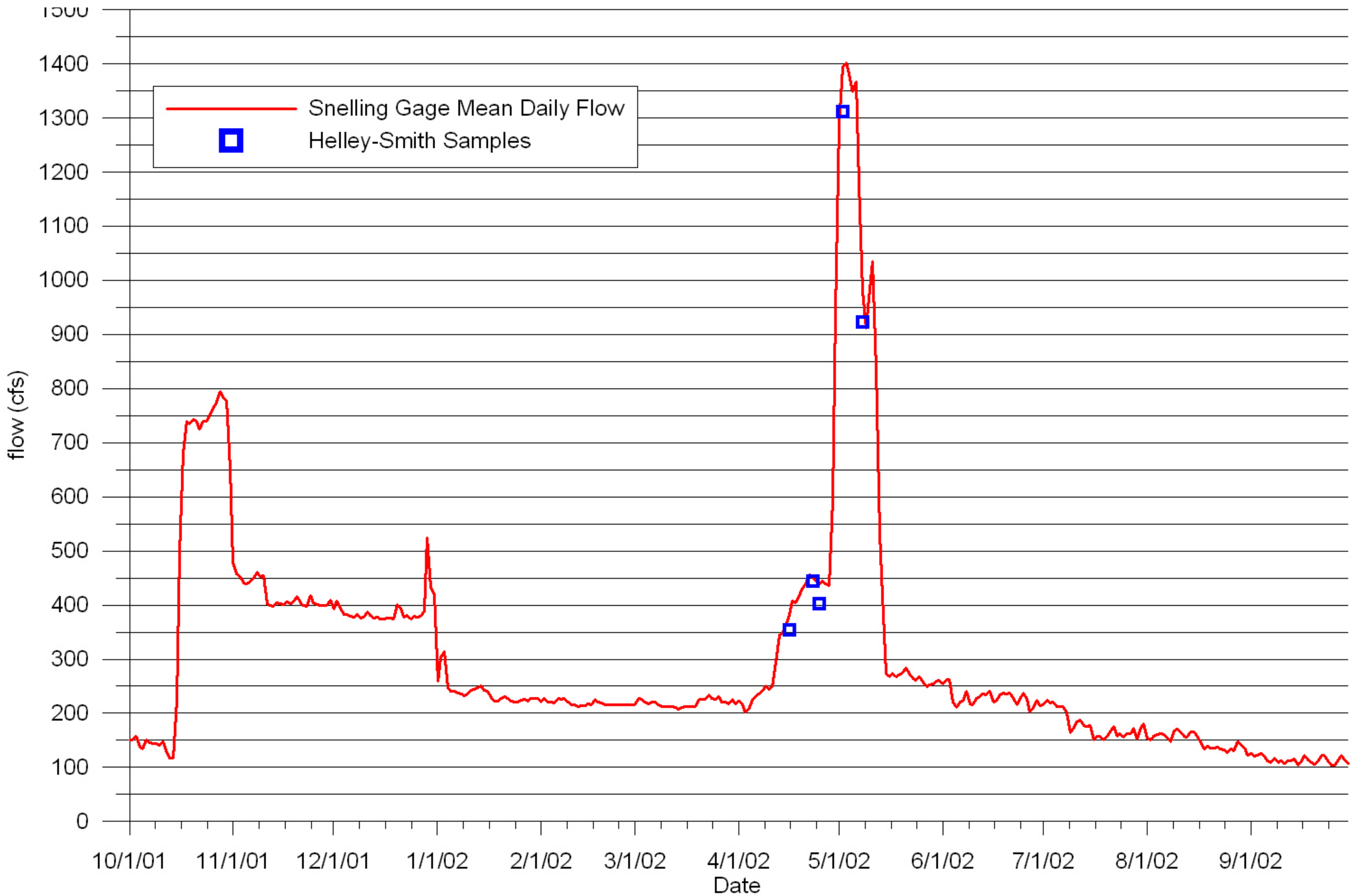


Figure 5.2.36. Snelling Gage Mean Daily Flow Hydrograph with Helley-Smith Sample Points

Figure 5.2.36

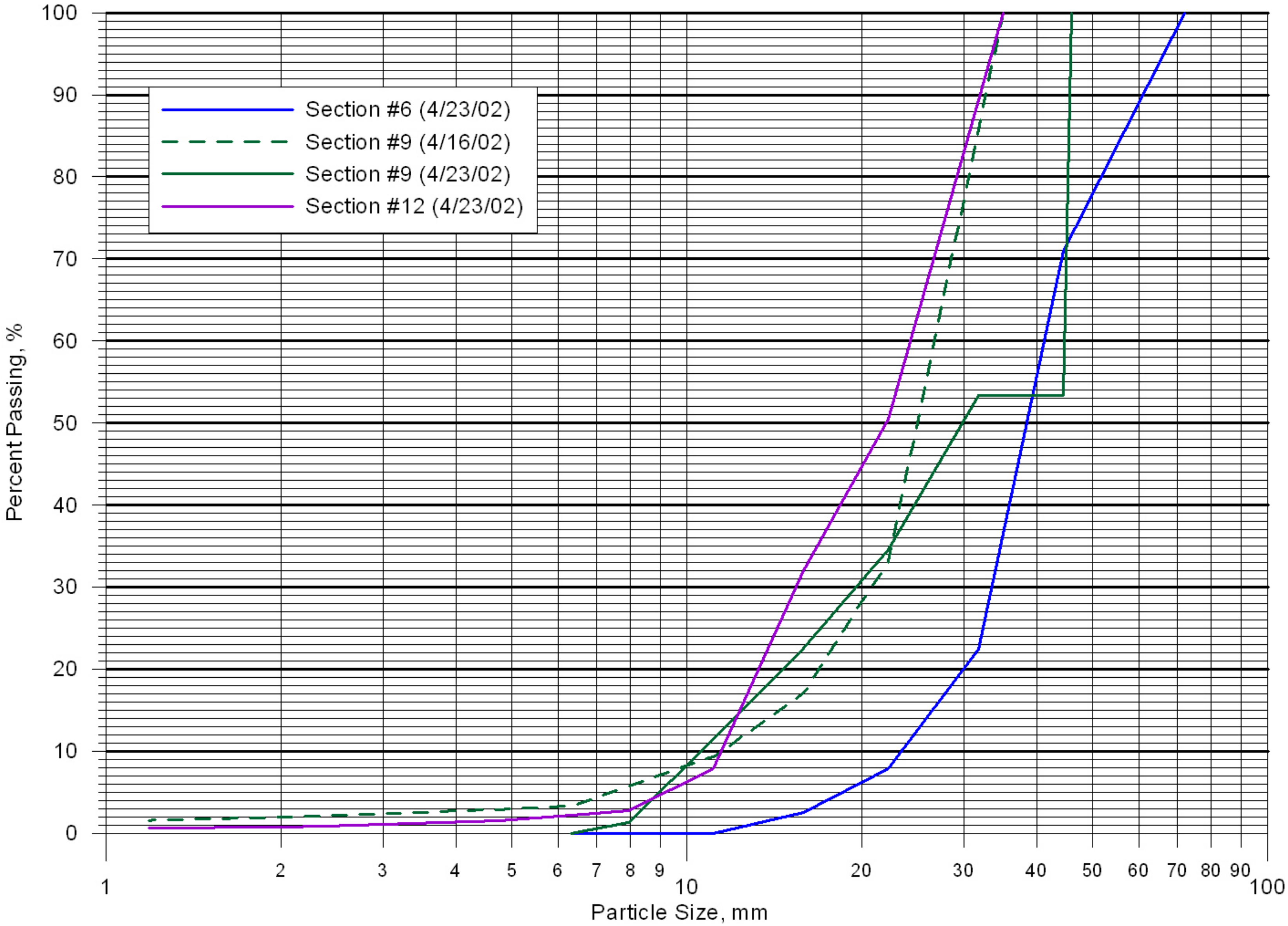


Figure 5.2.37. Helley-Smith Sample Sieve Analysis Results, Riffles 4/16/02 (354cfs) and 4/23/02 (444cfs)

Figure 5.2.37

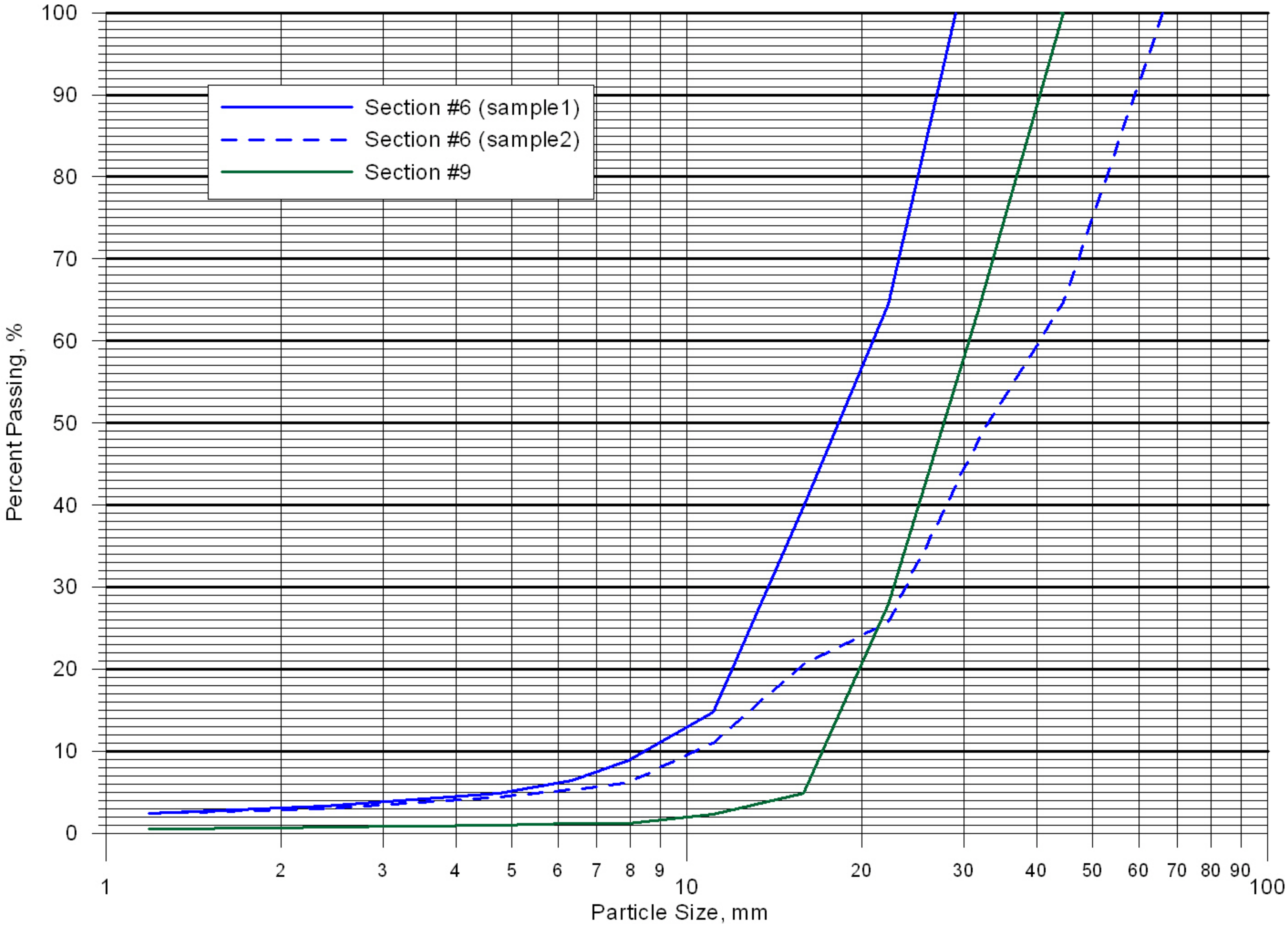


Figure 5.2.38. Helley-Smith Sample Sieve Analysis Results, Riffles 5/02/02 (1,312cfs)

Figure 5.2.38

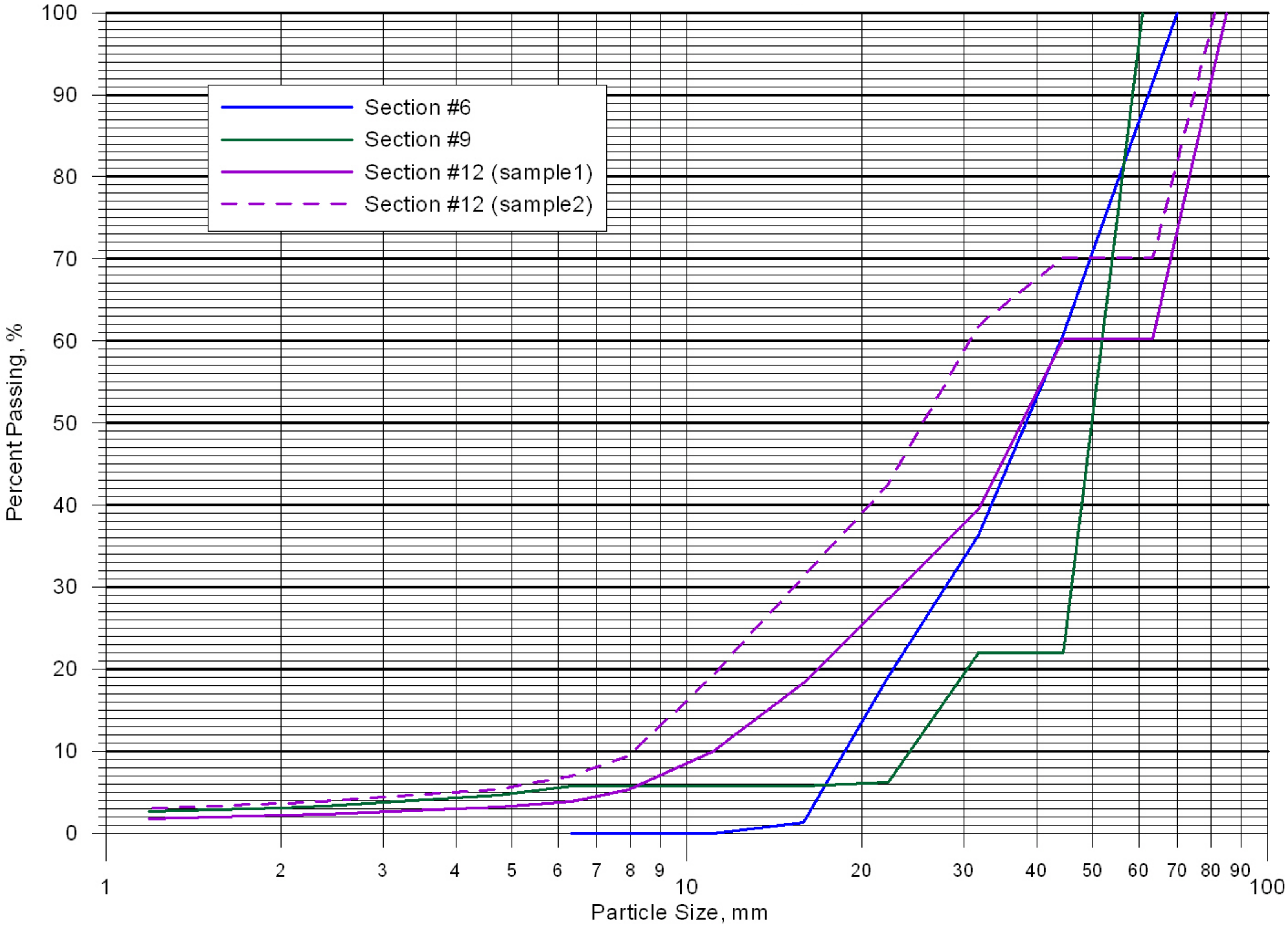


Figure 5.2.39. Helley-Smith Sample Sieve Analysis Results, Riffles 5/08/02 (923cfs)

Figure 5.2.39

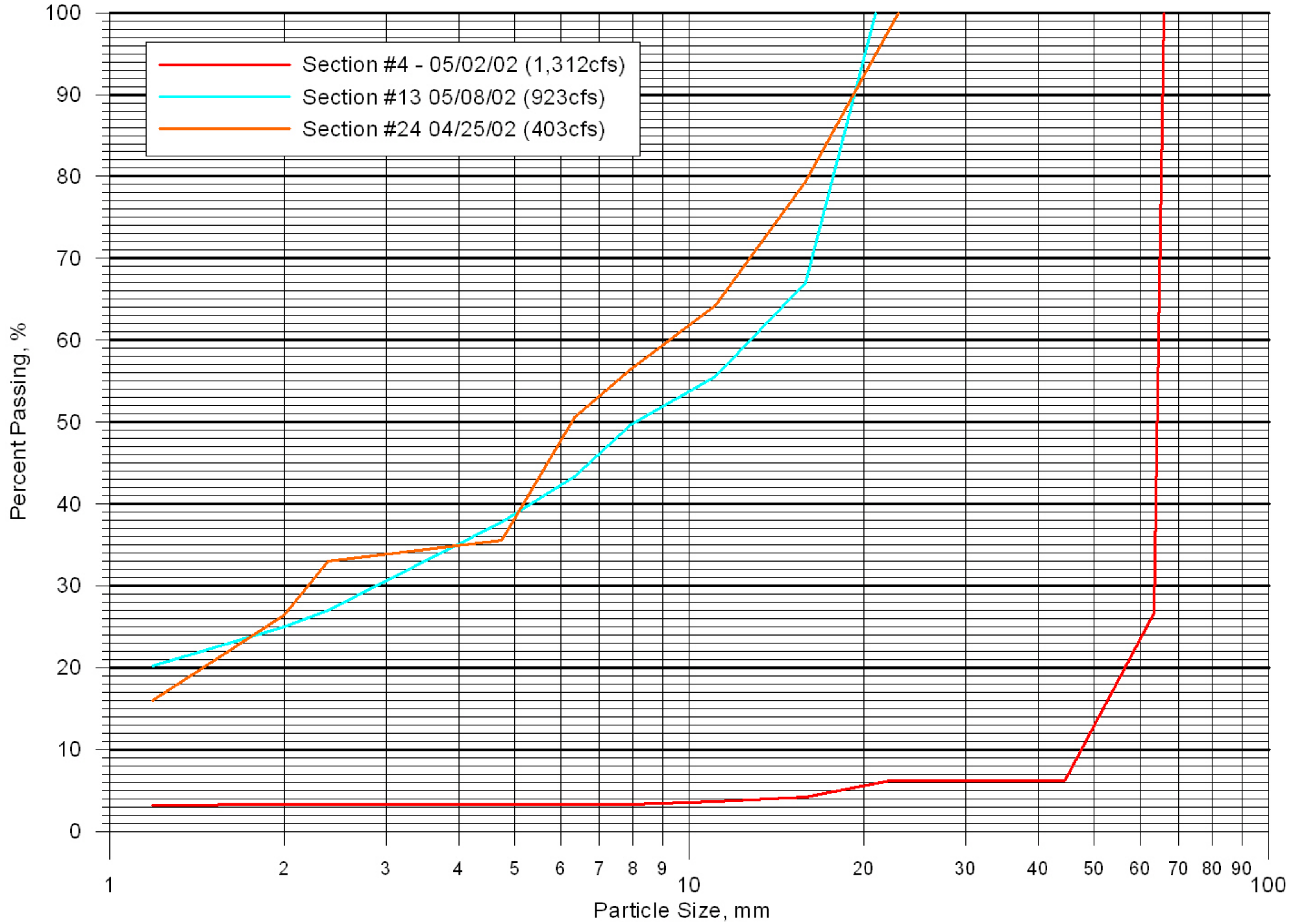
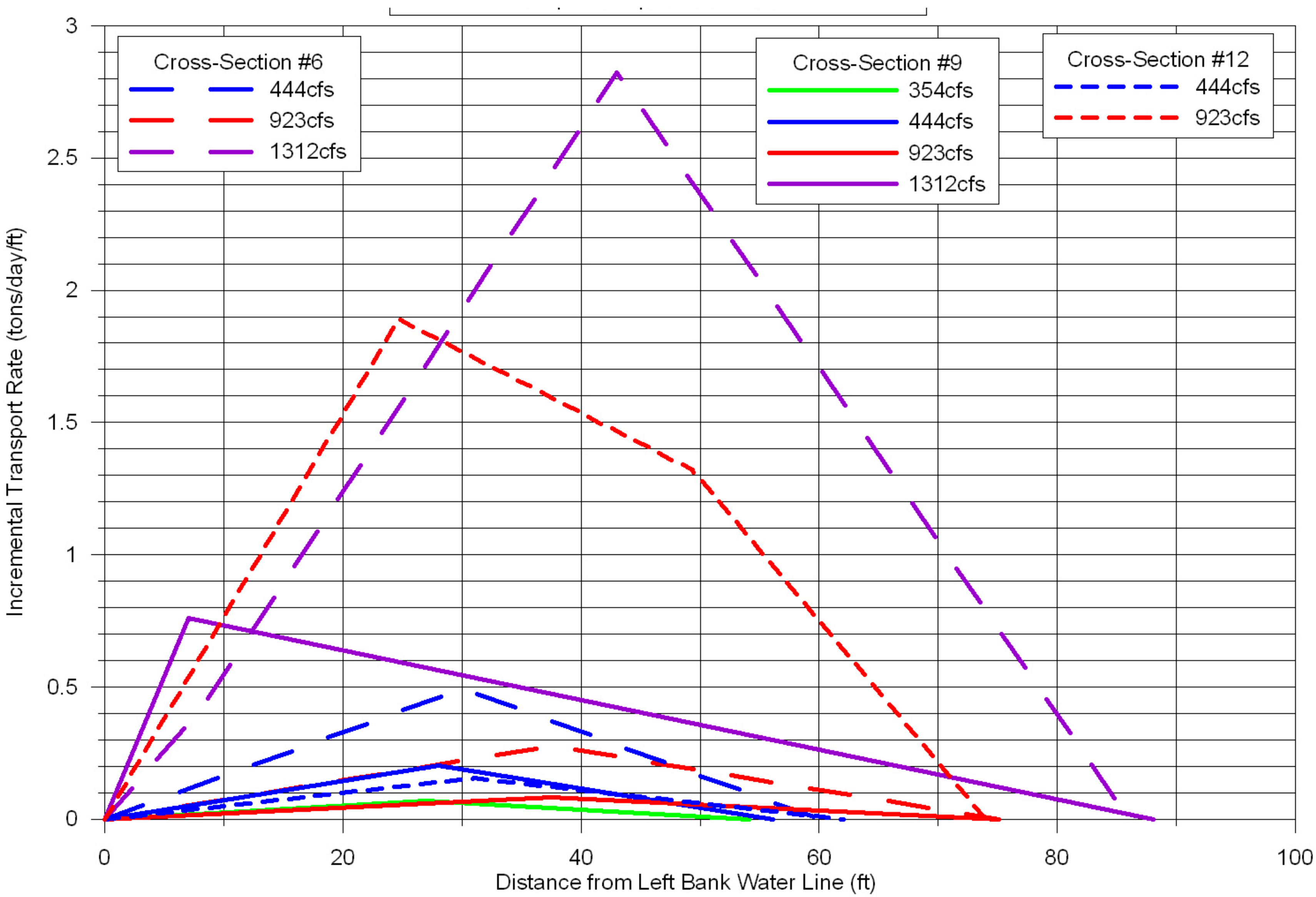


Figure 5.2.40. Helley-Smith Sample Sieve Analysis Results, Pools (#13, 24) and Transition (#4)

Figure 5.2.40



* - Area Under Curves Equal Bedload Transport Totals

Figure 5.2.41. Helley-Smith Sample Sections 9 and 12 Bedload Transport Profiles

Figure 5.2.41

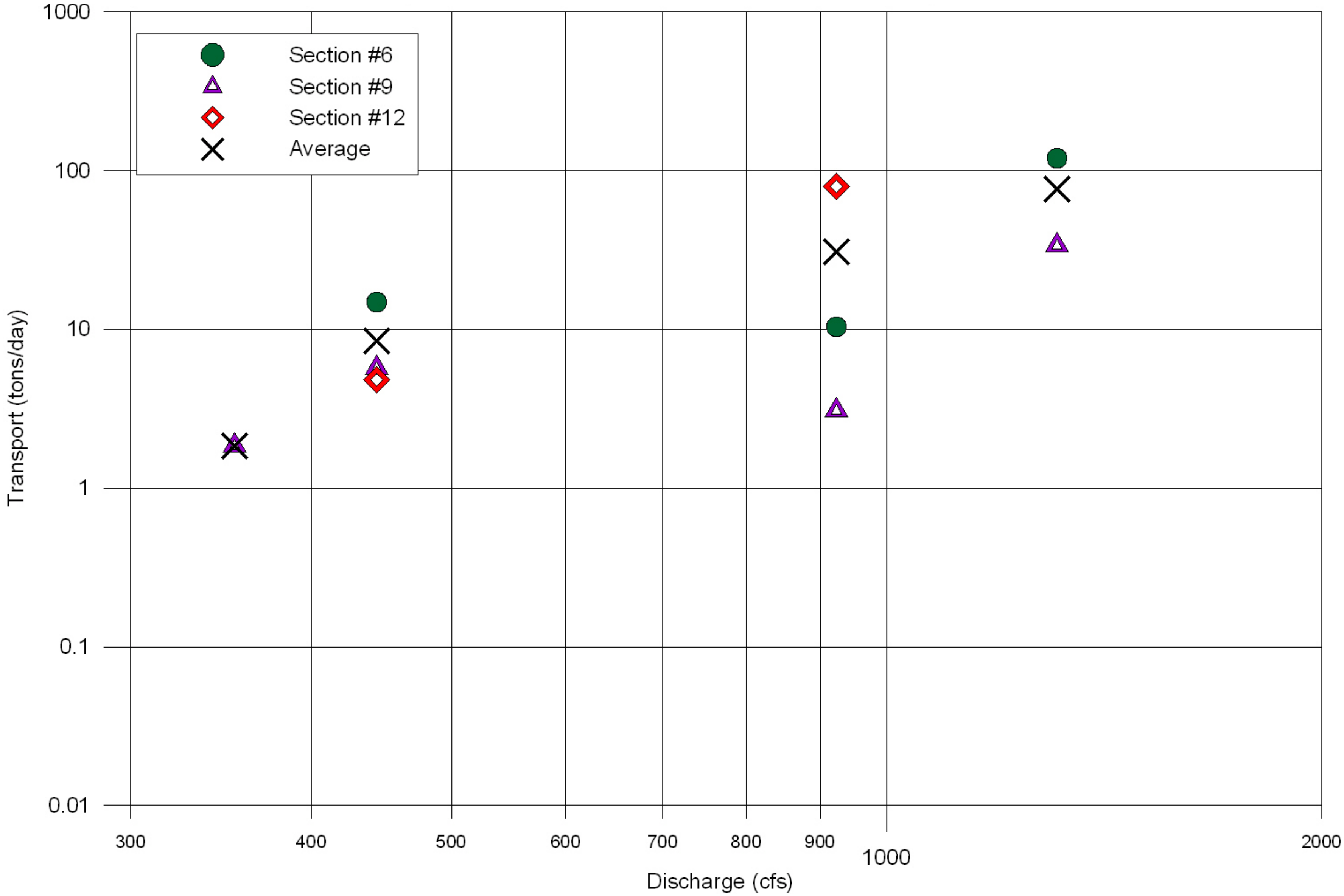


Figure 5.2.42. 2002 Riffle Section Discharge vs. Bedload Transport

Figure 5.2.42

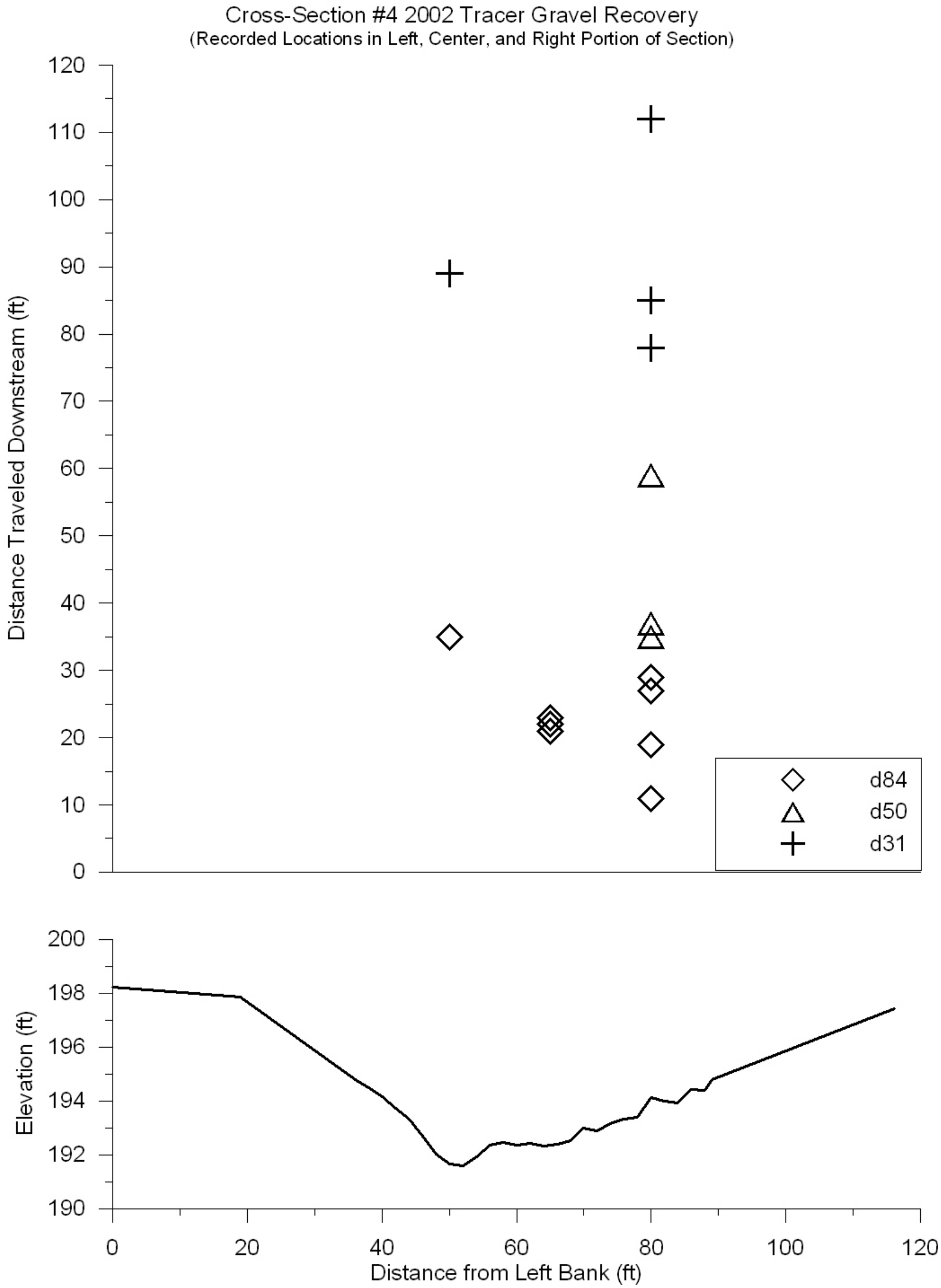


Figure 5.2.43. Section #4 2002 Tracer Gravel Recovery

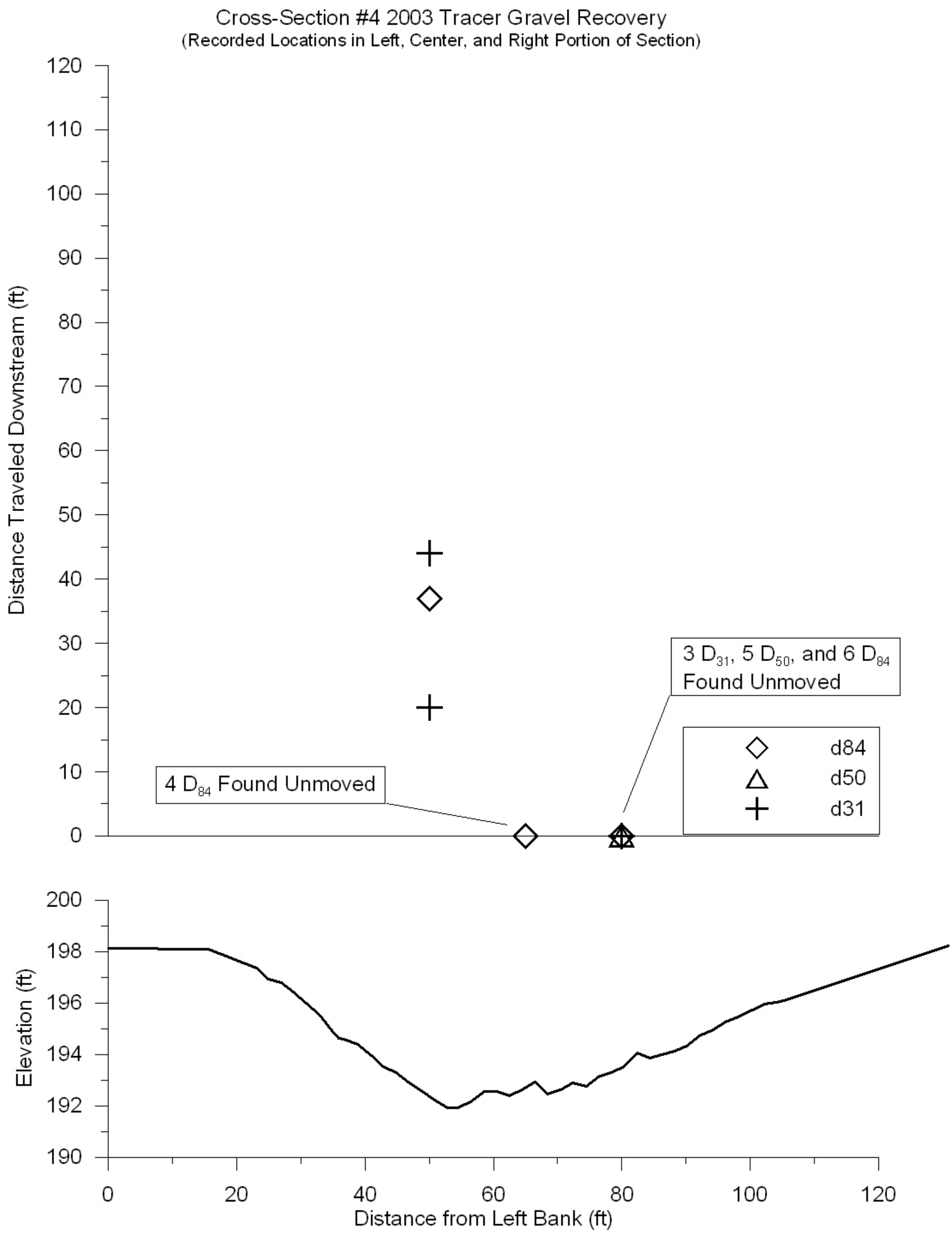


Figure 5.2.44. Section #4 2003 Tracer Gravel Recovery

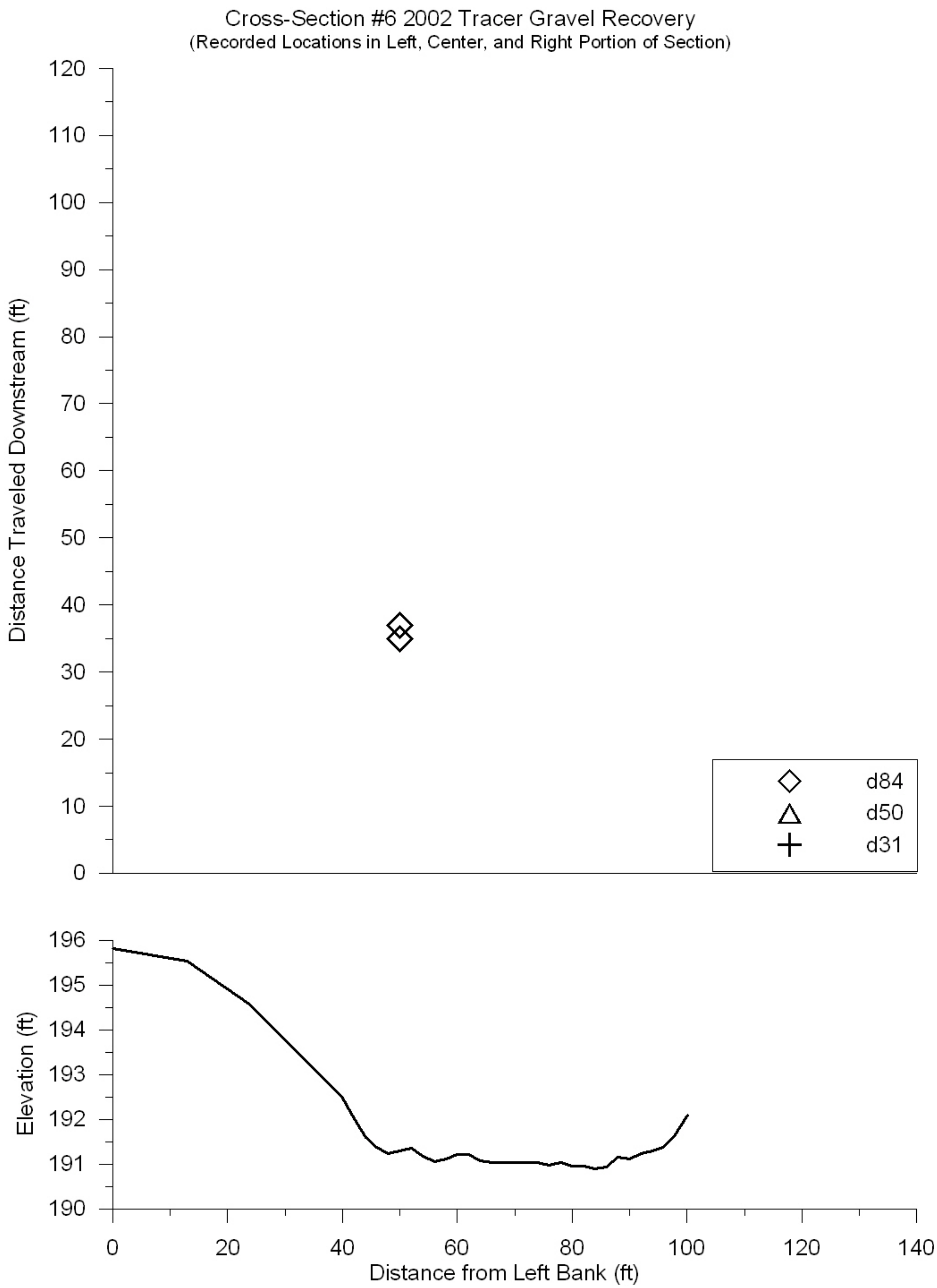


Figure 5.2.45. Section #6 2002 Tracer Gravel Recovery

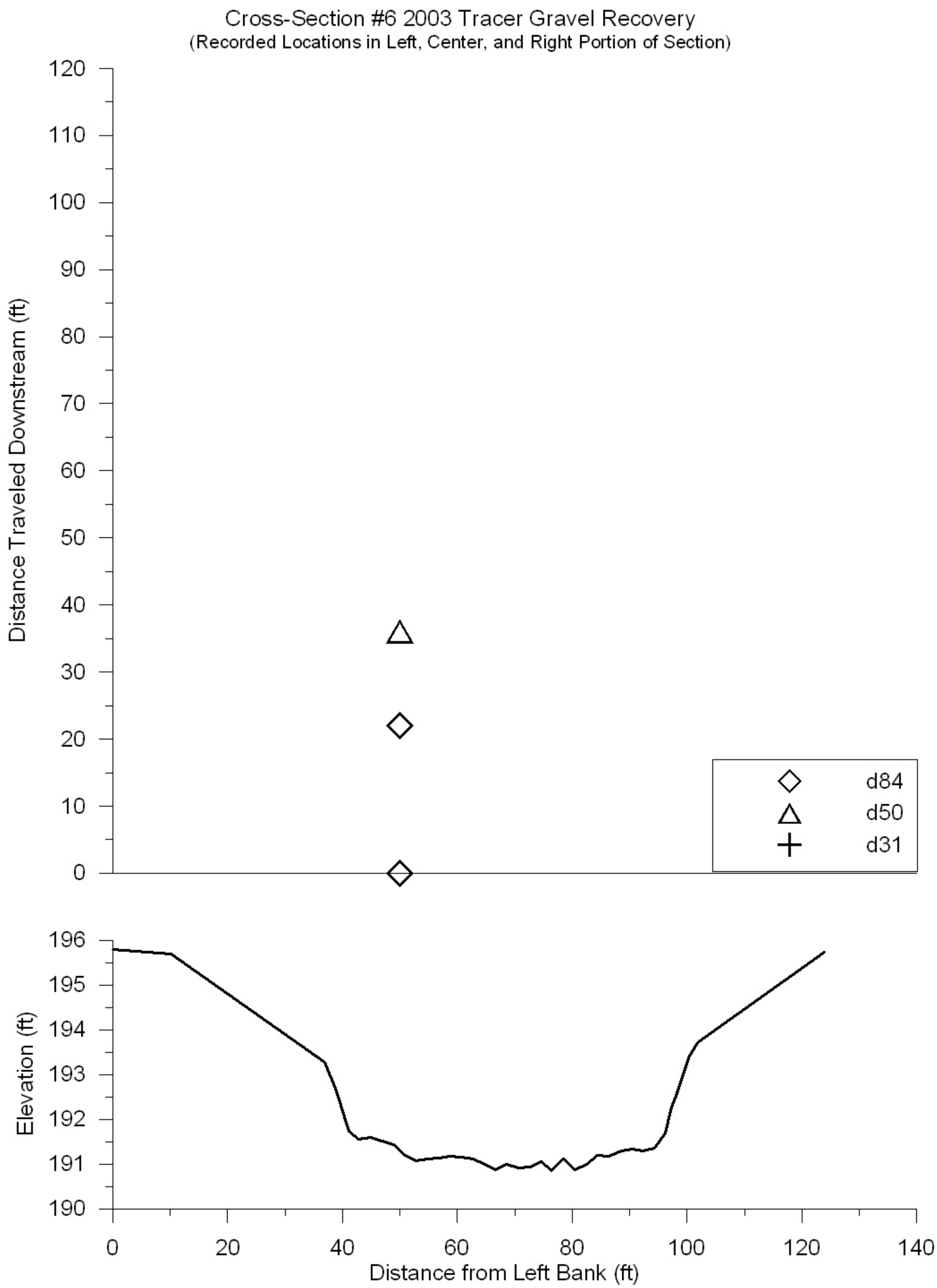


Figure 5.2.46. Section #6 2003 Tracer Gravel Recovery

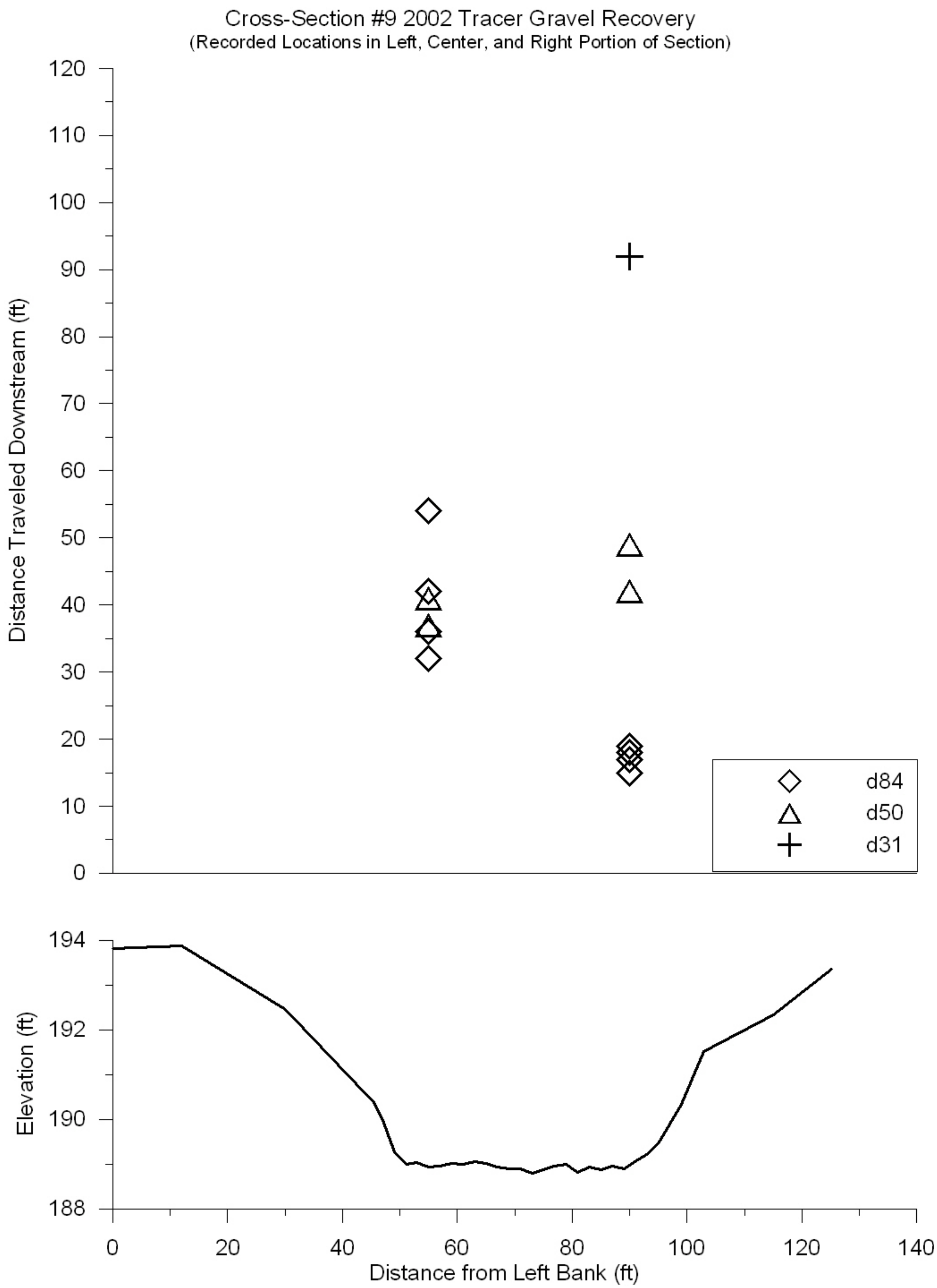


Figure 5.2.47. Section #9 2002 Tracer Gravel Recovery

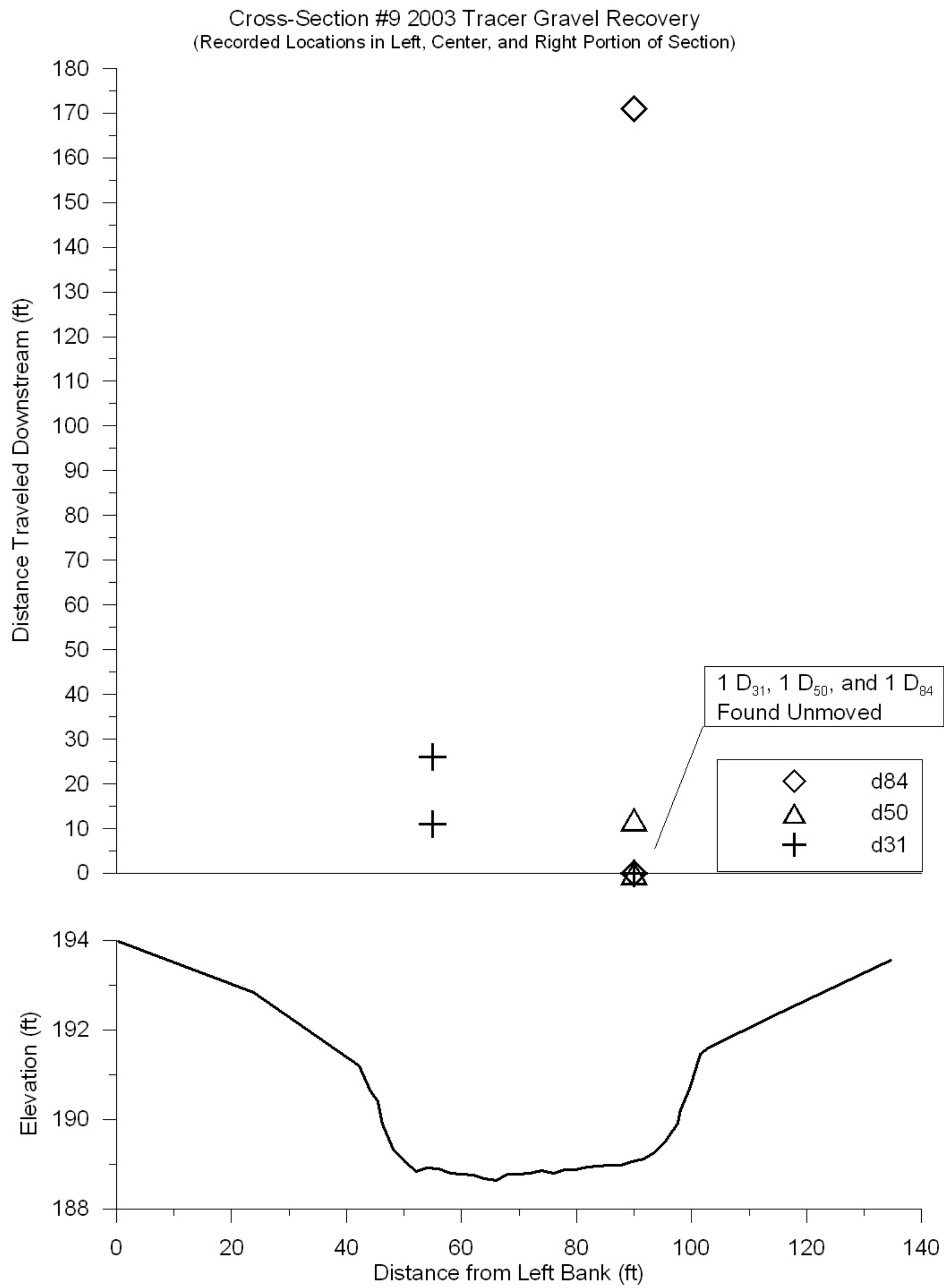


Figure 5.2.48. Section #9 2003 Tracer Gravel Recovery

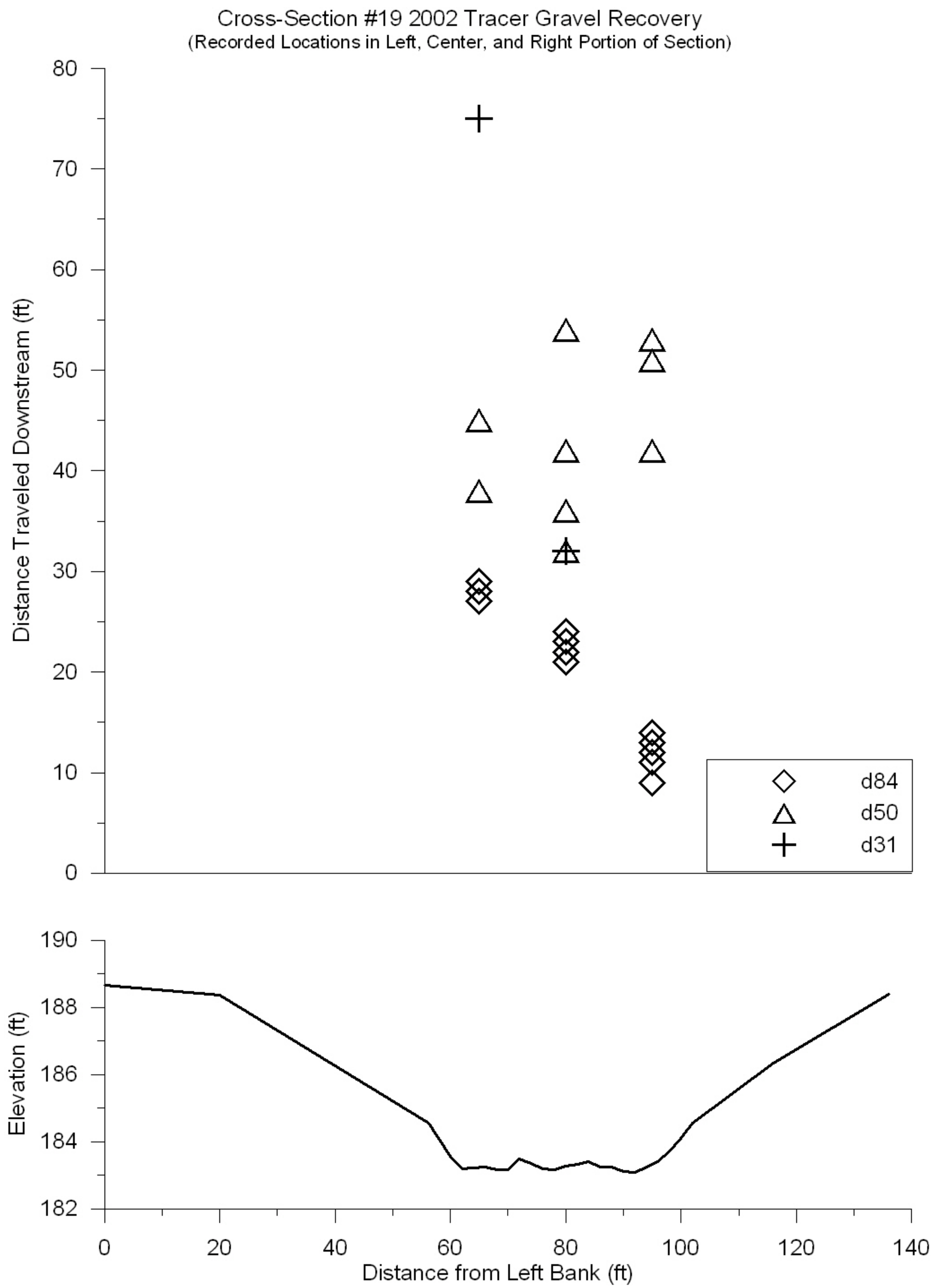


Figure 5.2.49. Section #19 2002 Tracer Gravel Recovery

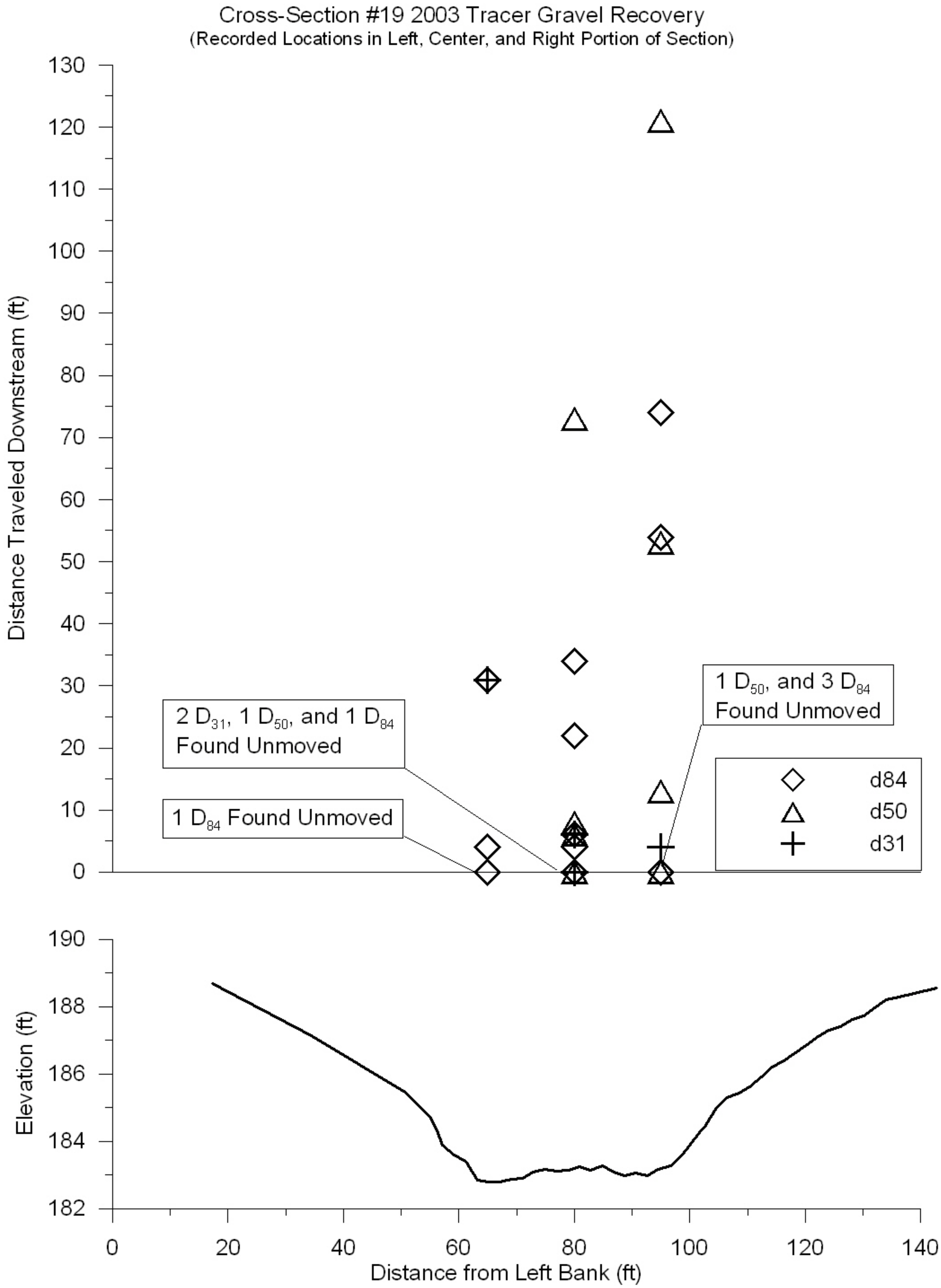


Figure 5.2.50. Section #19 2003 Tracer Gravel Recovery

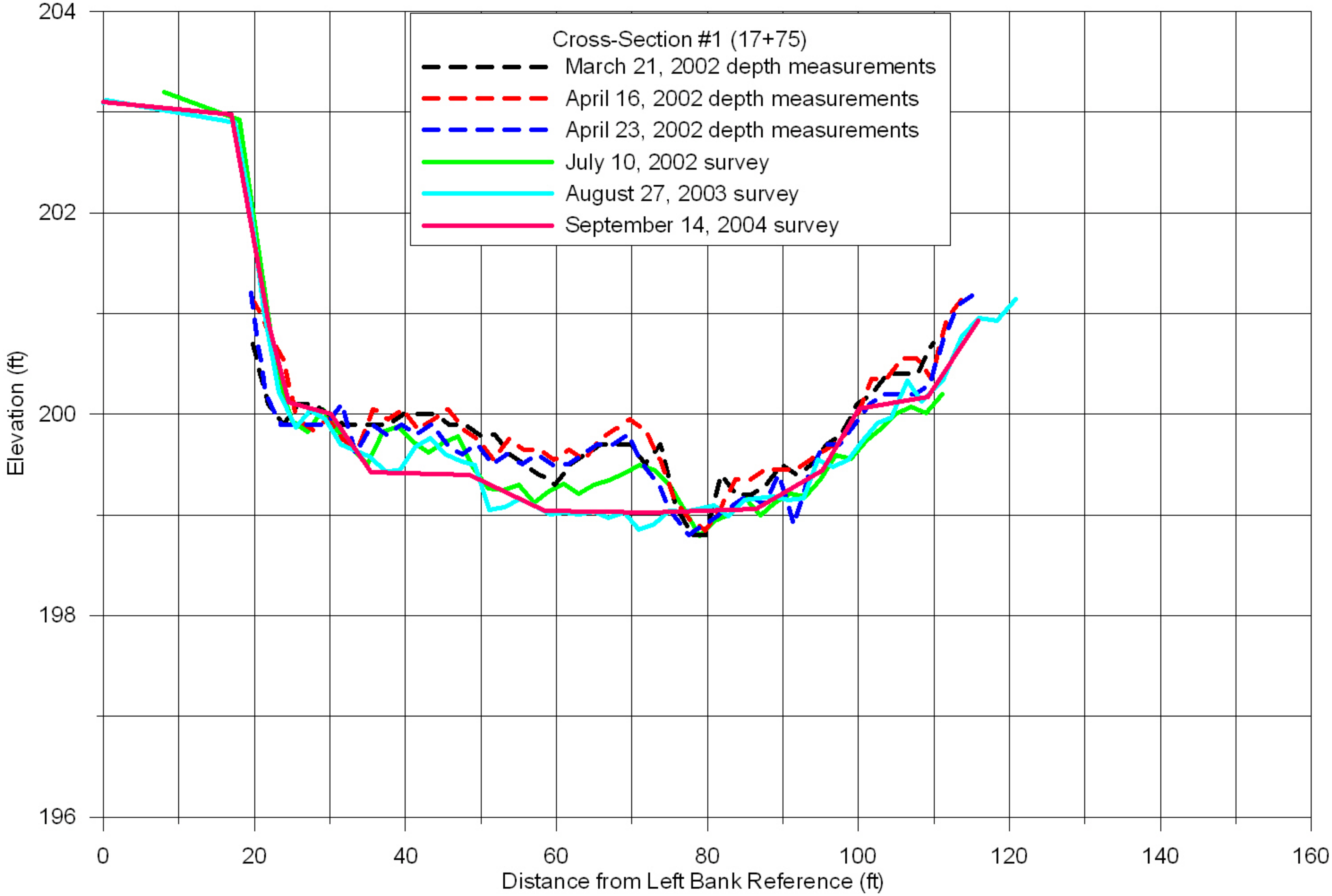


Figure 5.2.51. Cross-Section #1 Survey Profile

Figure 5.2.51

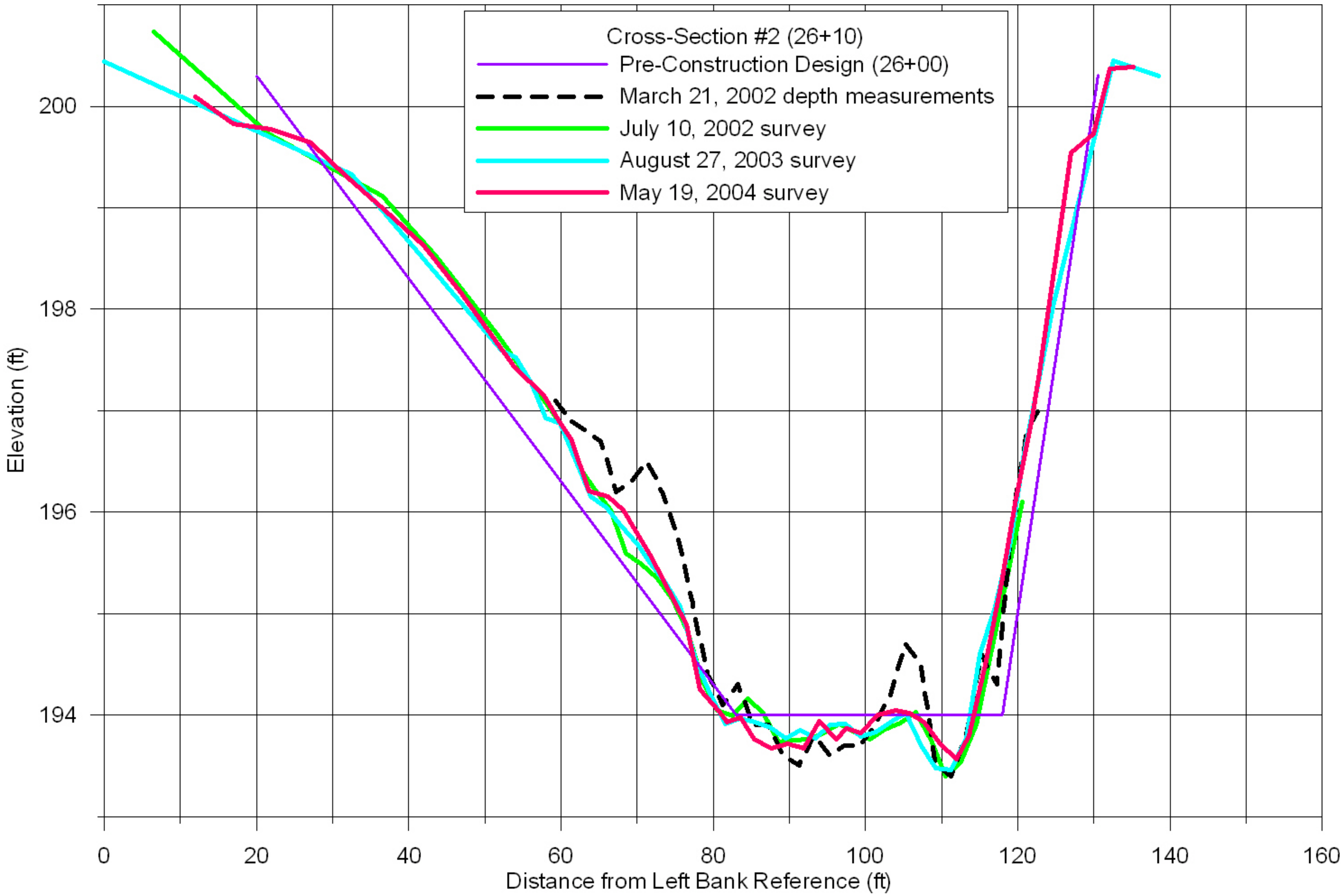


Figure 5.2.52. Cross-Section #2 Survey Profile

Figure 5.2.52

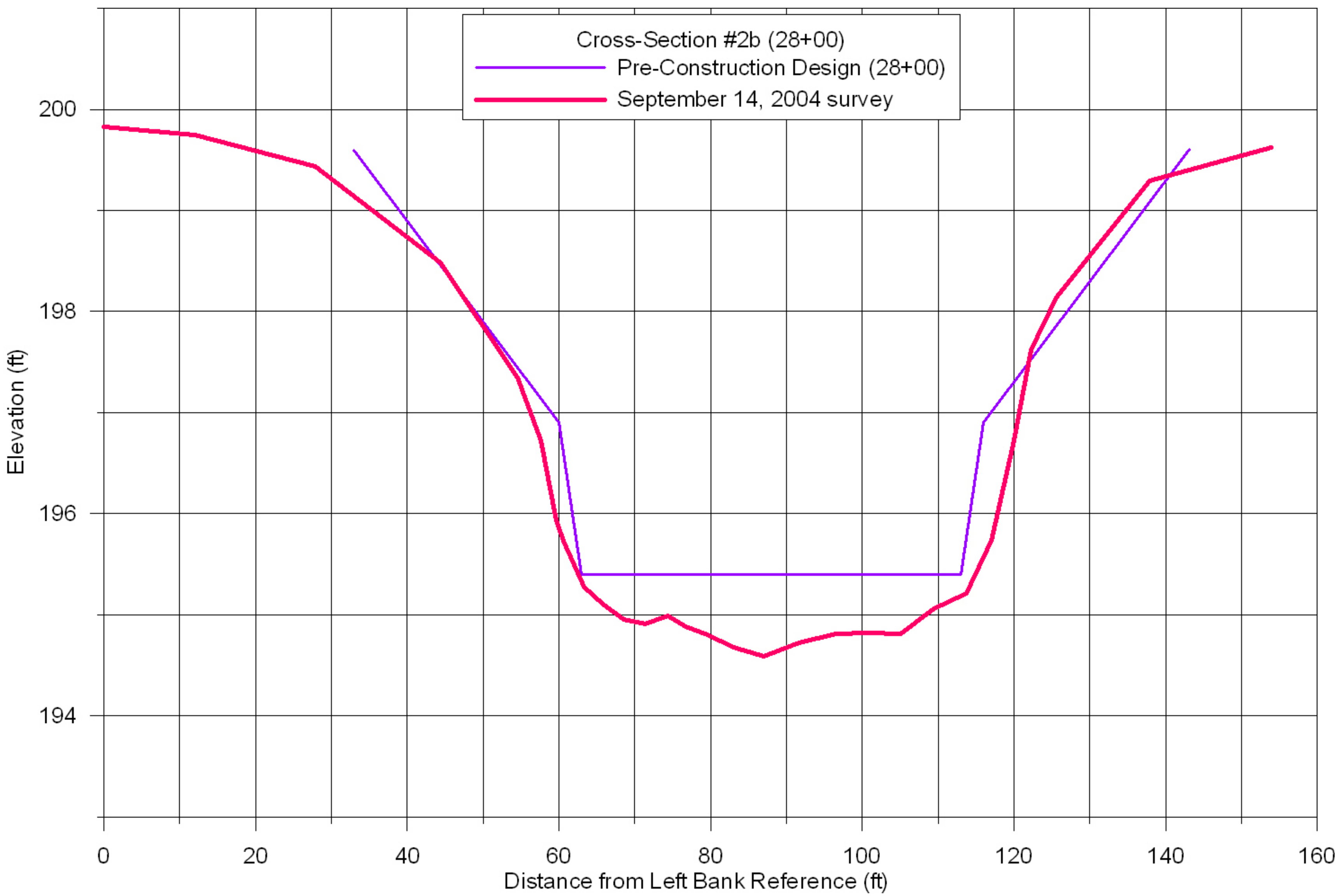


Figure 5.2.53. Cross-Section #2b Survey Profile

Figure 5.2.53

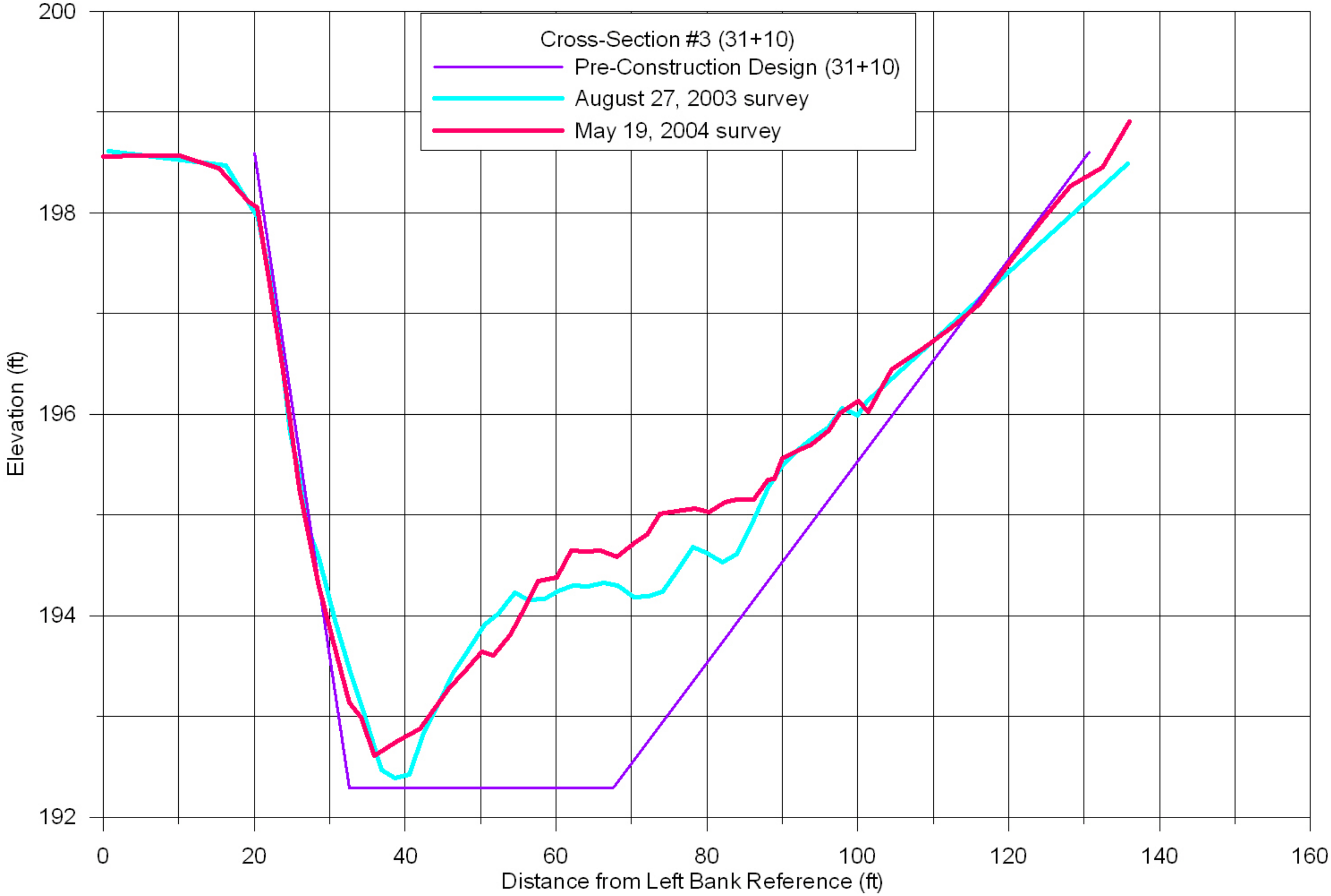


Figure 5.2.54. Cross-Section #3 Survey Profile

Figure 5.2.54

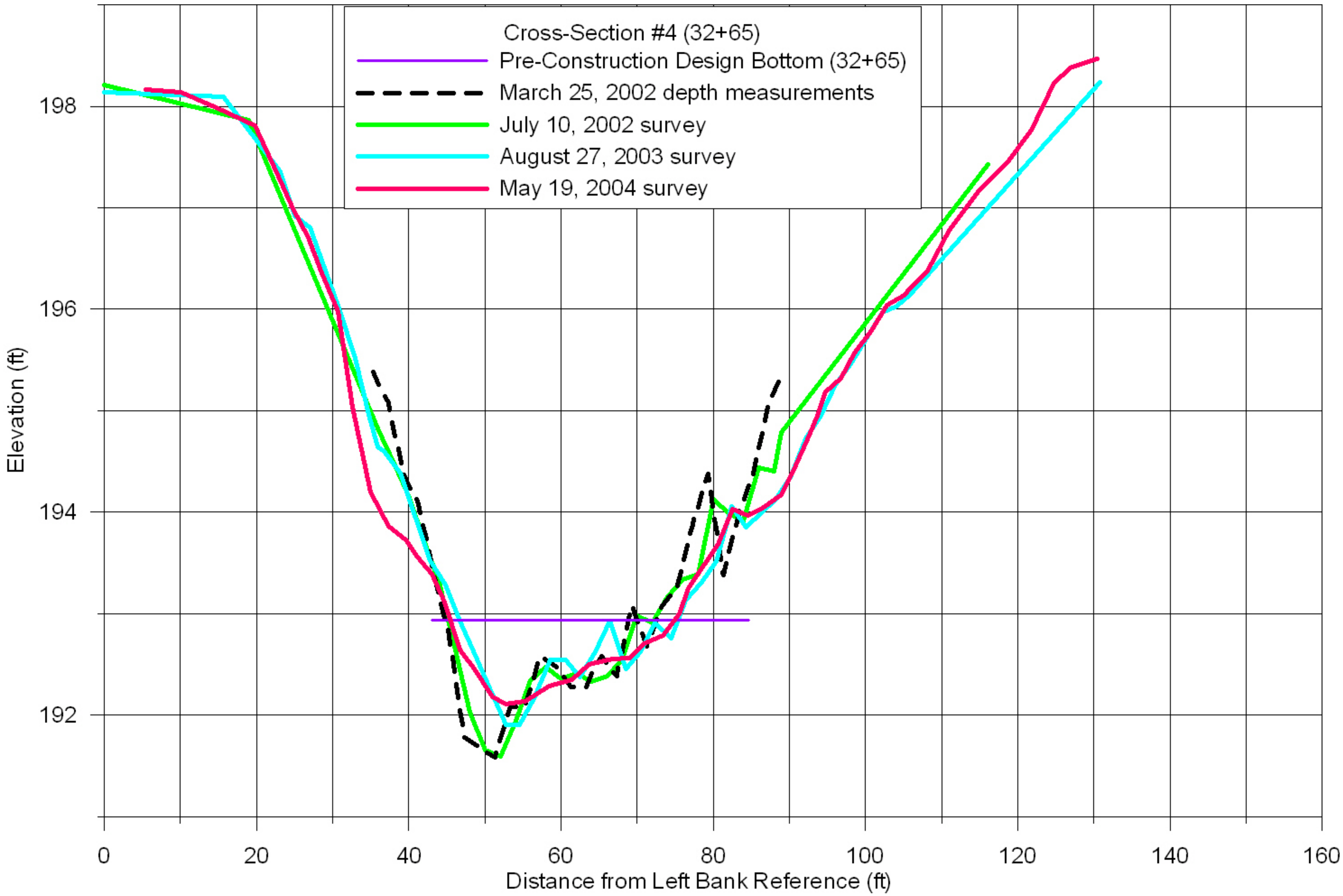


Figure 5.2.55. Cross-Section #4 Survey Profile

Figure 5.2.55

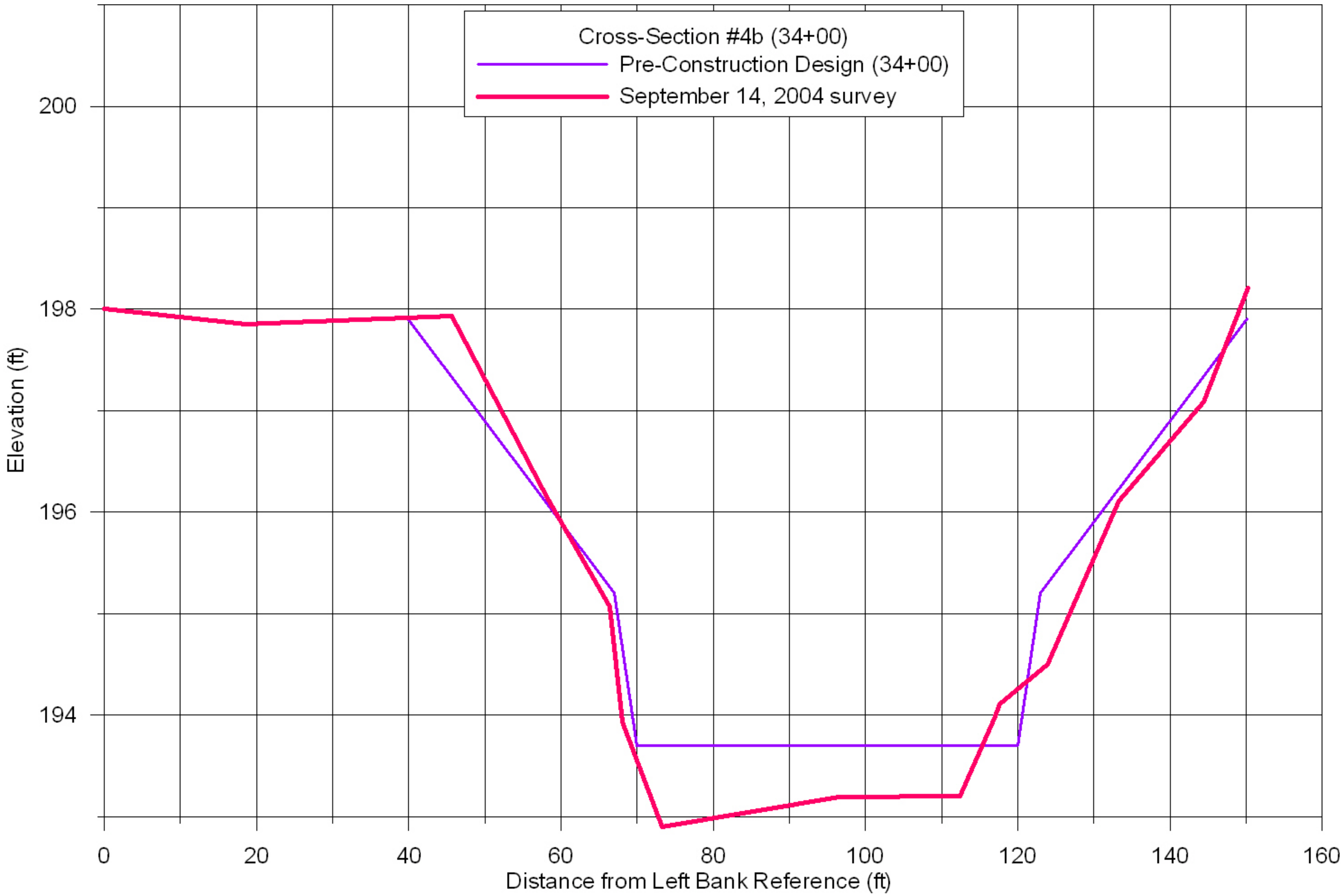


Figure 5.2.56. Cross-Section #4b Survey Profile

Figure 5.2.56

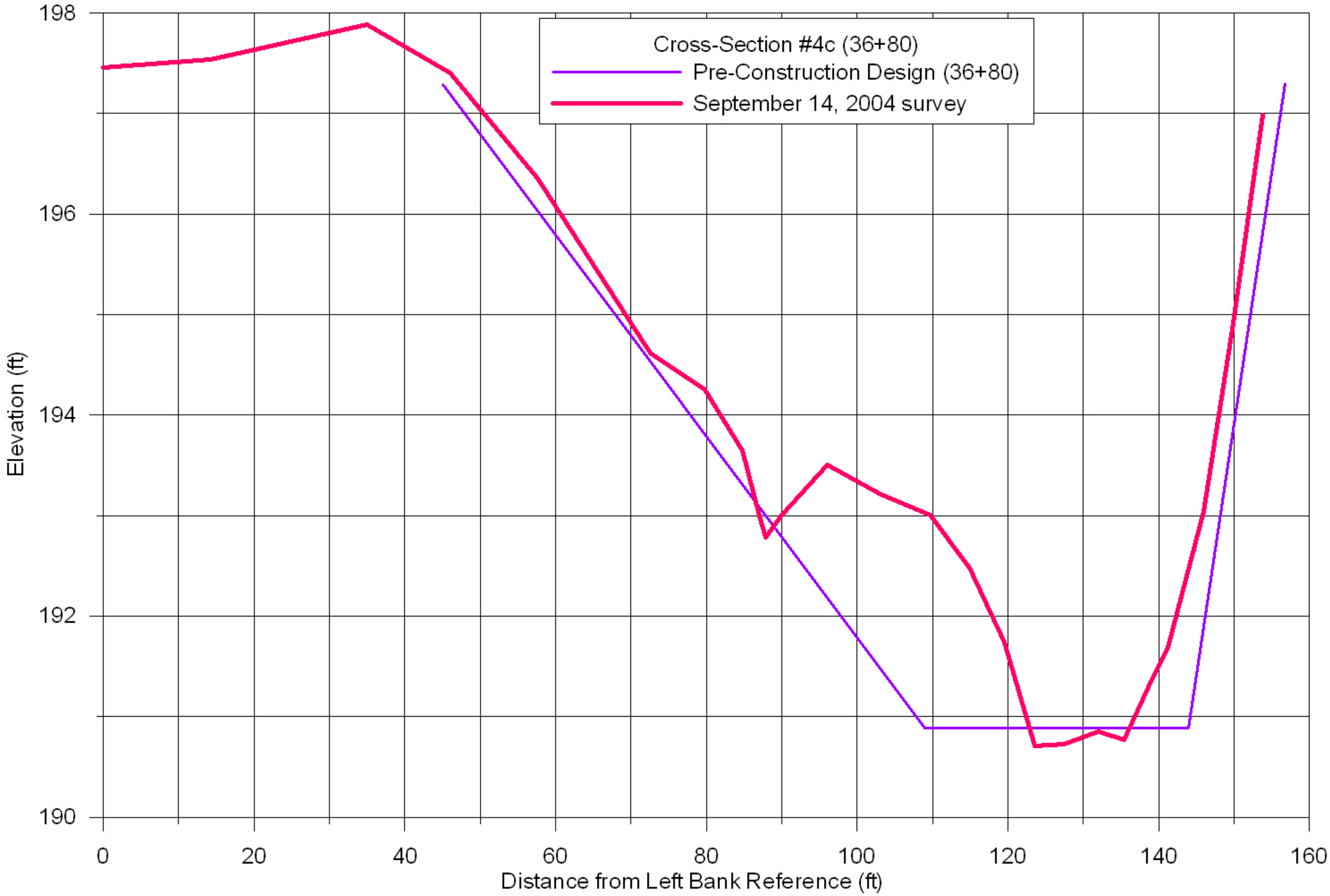


Figure 5.2.57. Cross-Section #4c Survey Profile

Figure 5.2.57

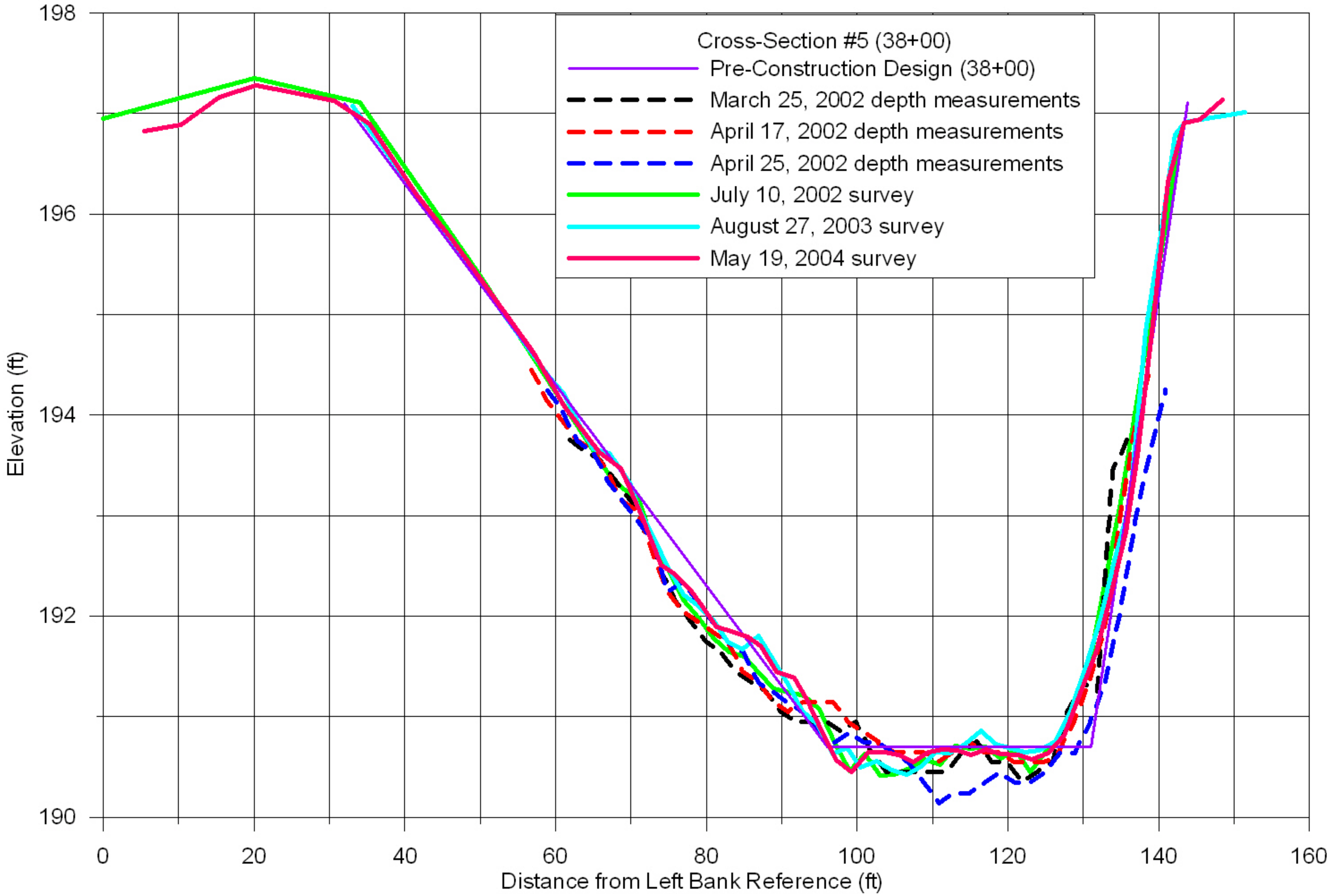


Figure 5.2.58. Cross-Section #5 Survey Profile

Figure 5.2.58

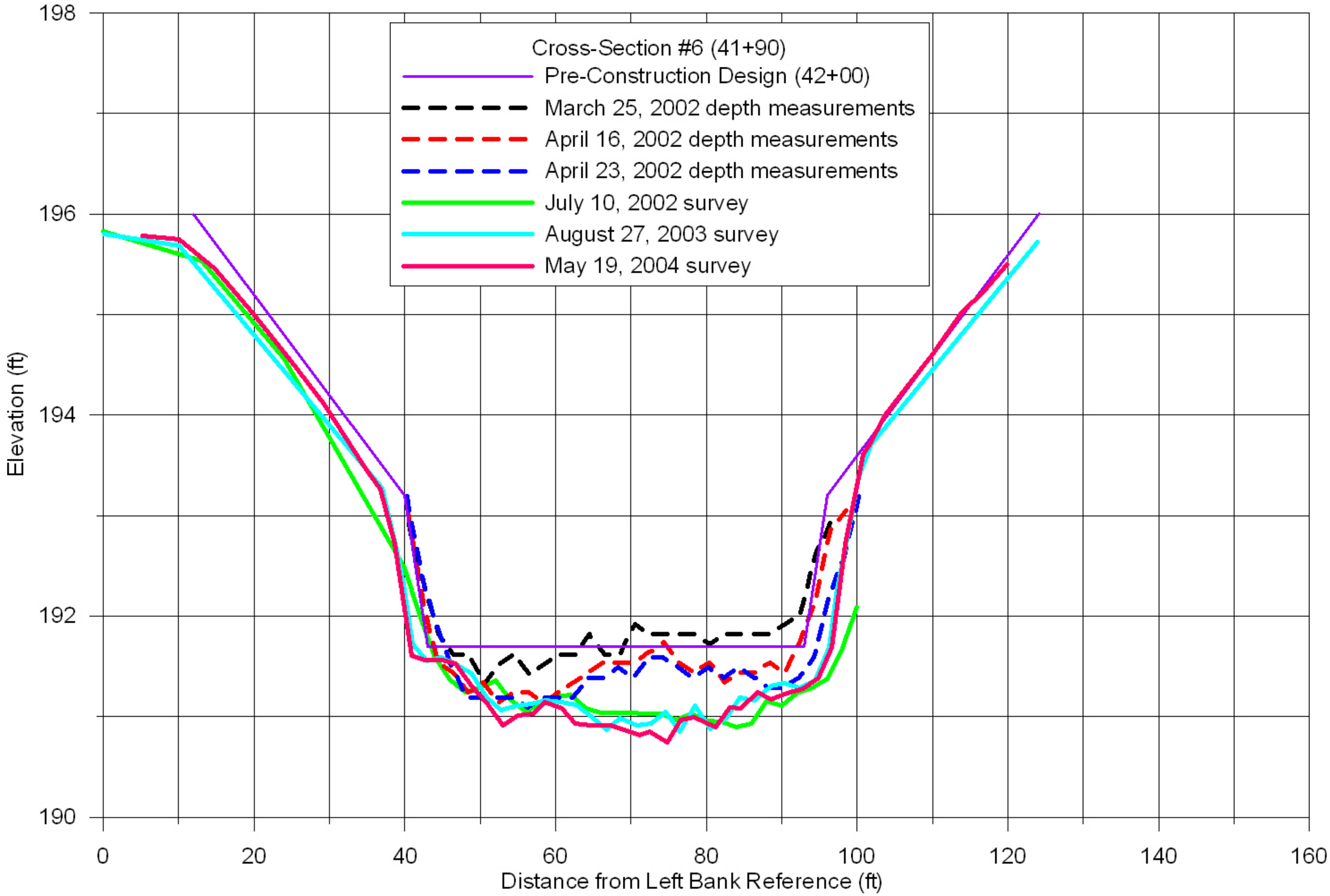


Figure 5.2.59. Cross-Section #6 Survey Profile

Figure 5.2.59

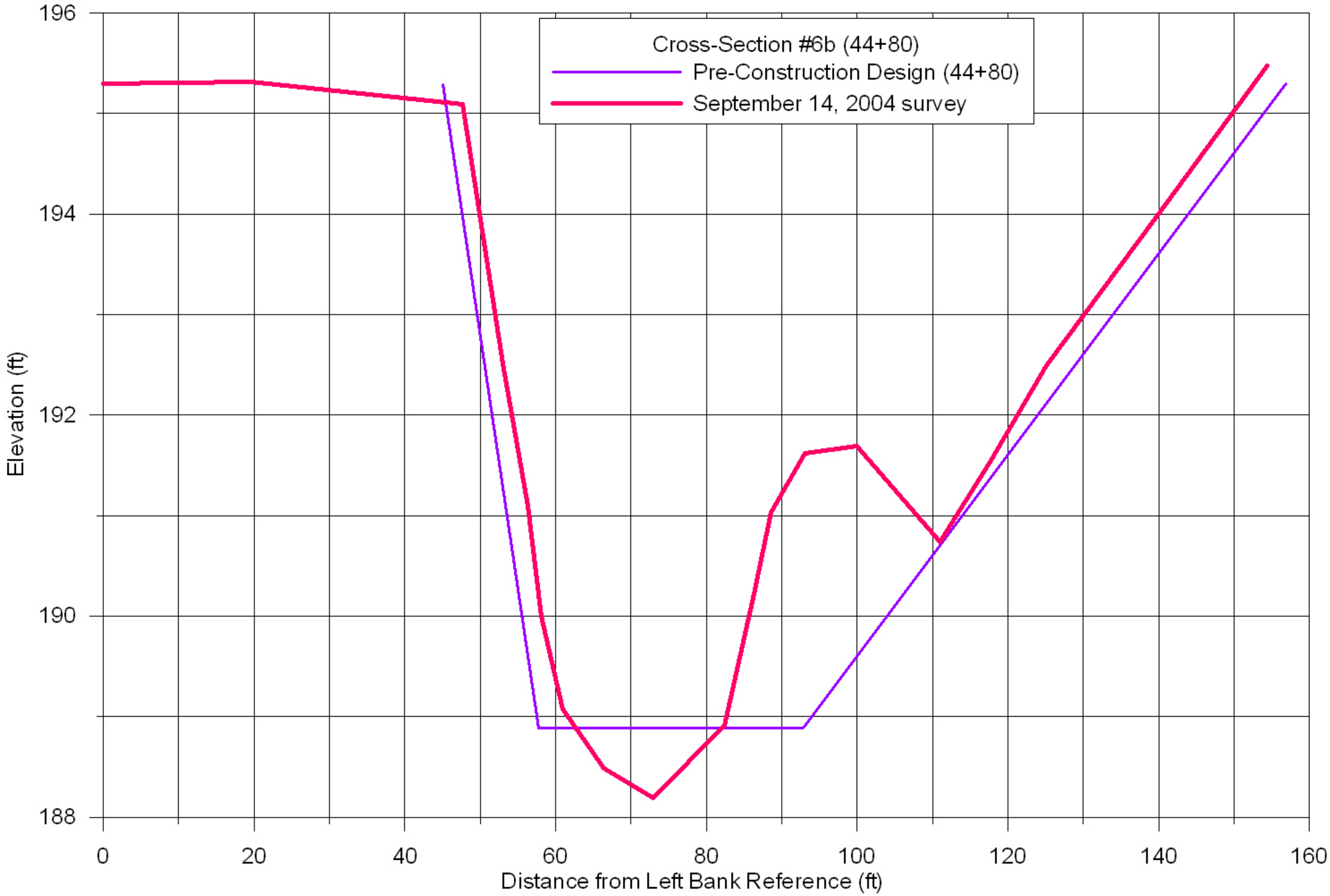


Figure 5.2.60. Cross-Section #6b Survey Profile

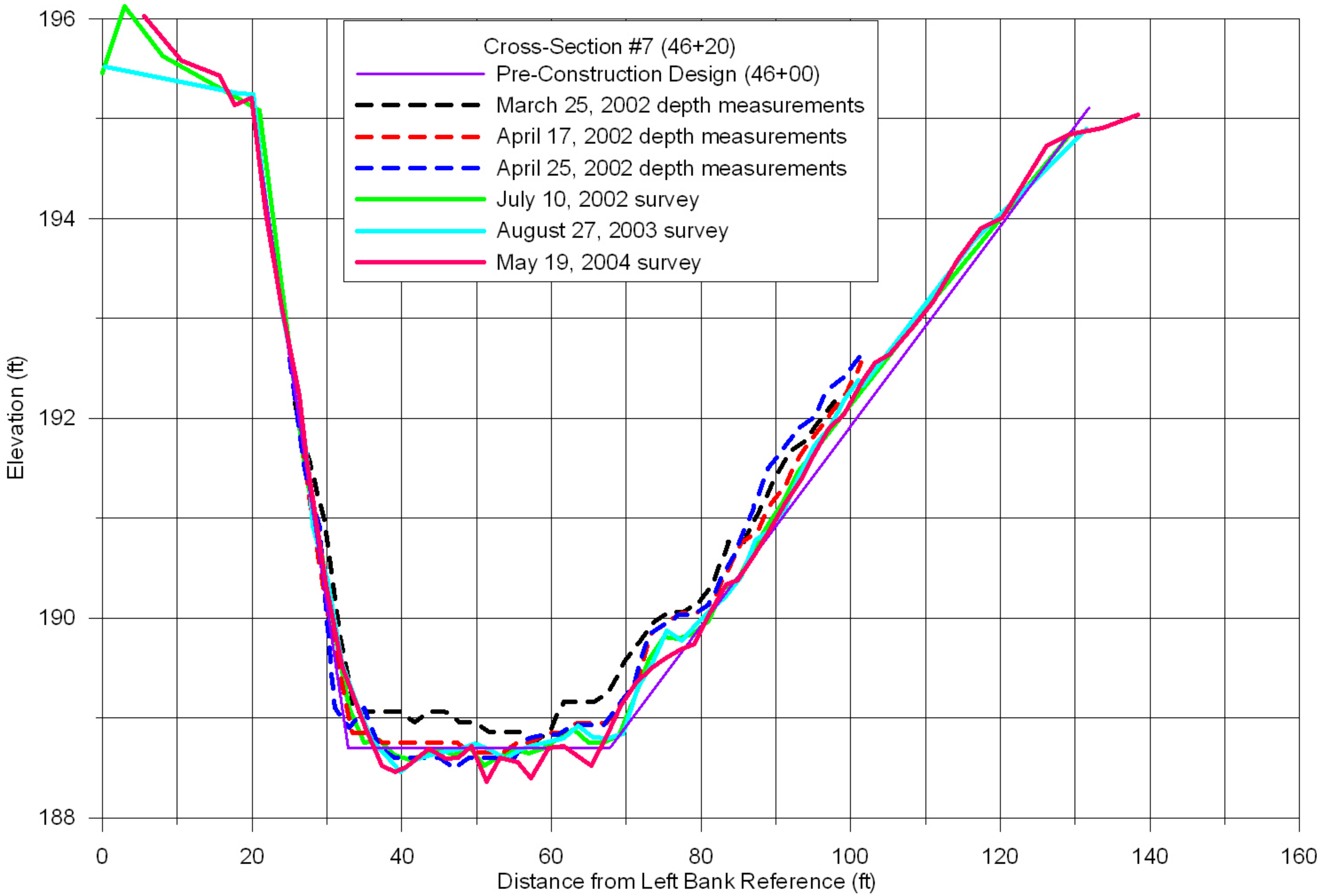


Figure 5.2.61. Cross-Section #7 Survey Profile

Figure 5.2.61

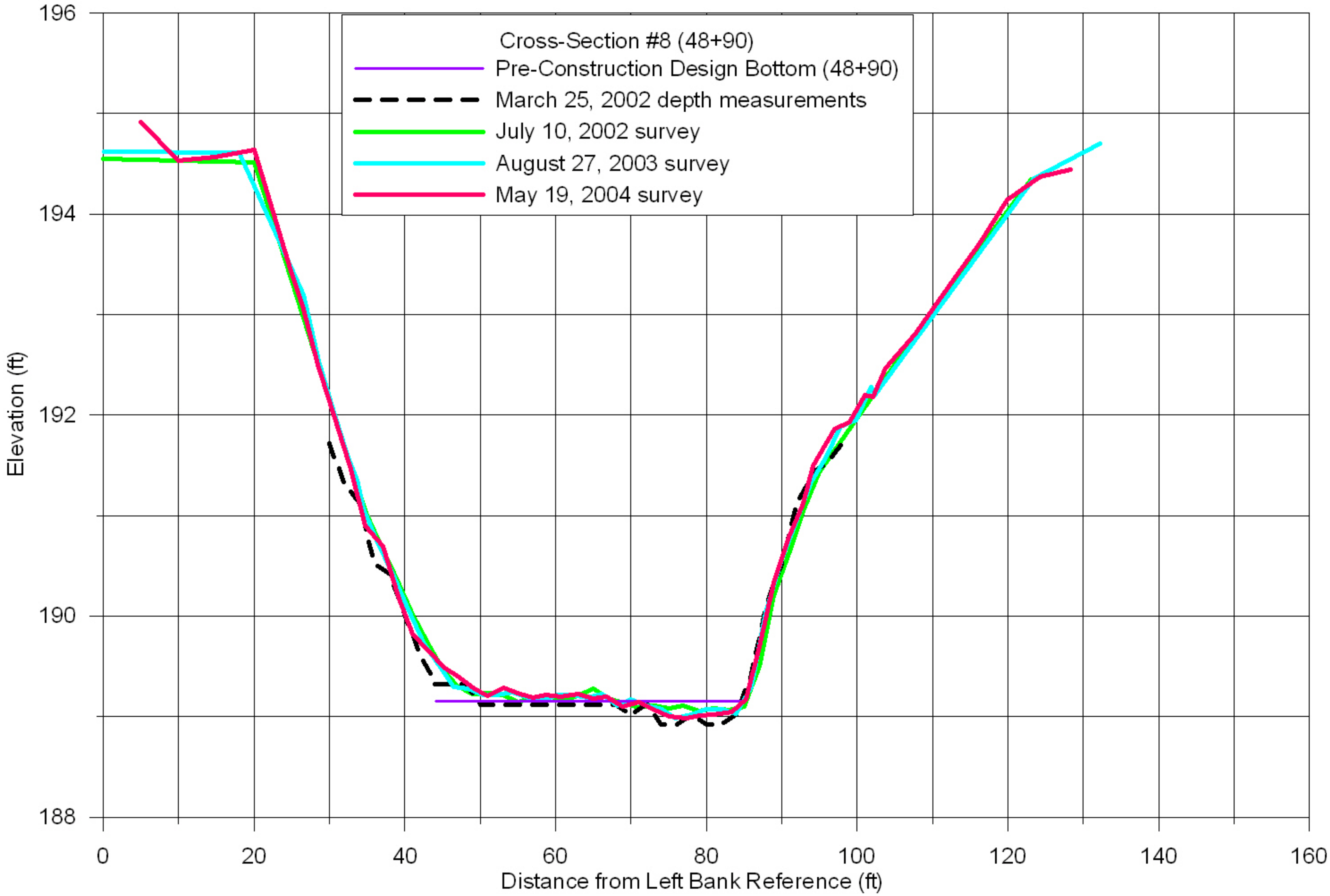


Figure 5.2.62. Cross-Section #8 Survey Profile

Figure 5.2.62

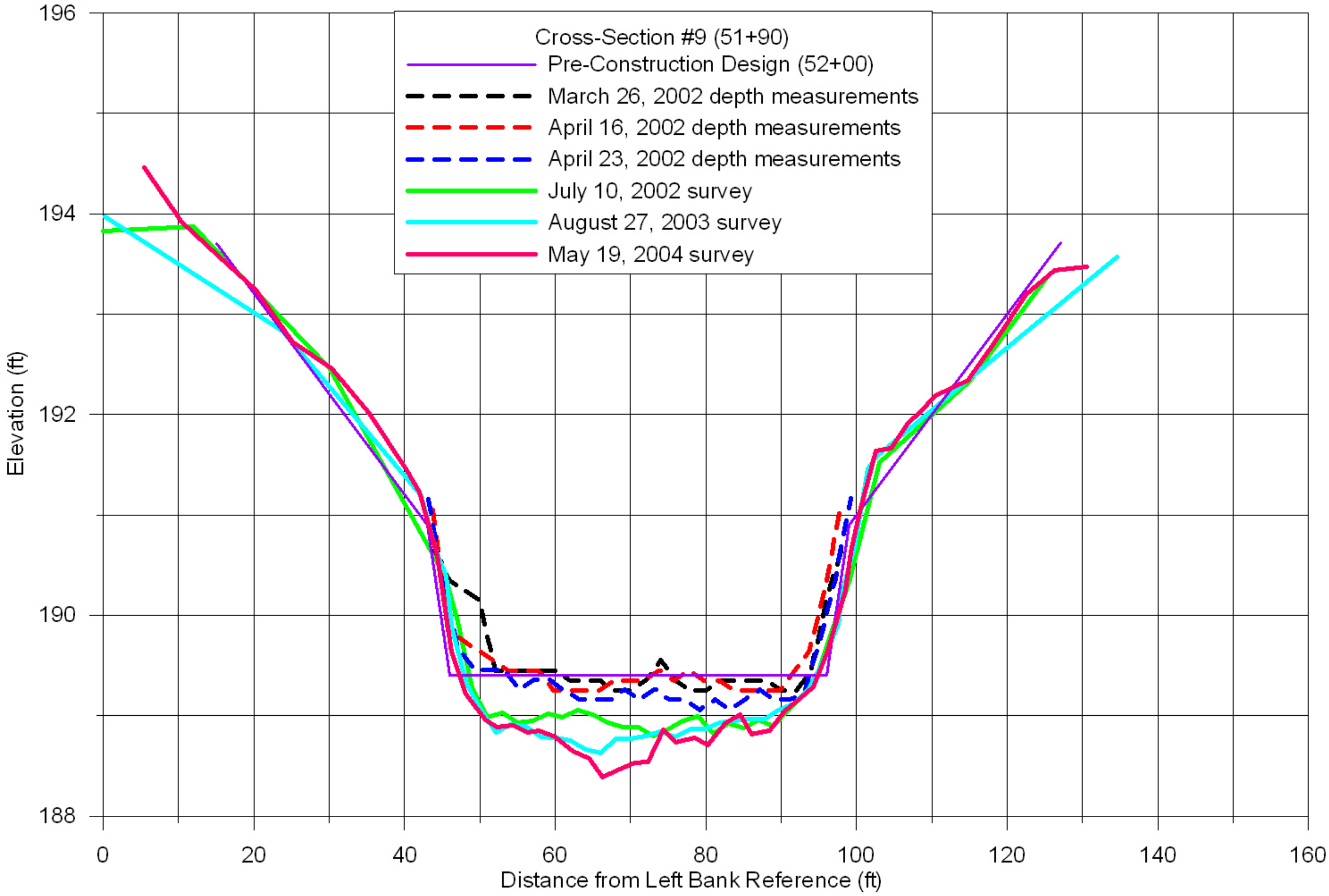


Figure 5.2.63. Cross-Section #9 Survey Profile

Figure 5.2.63

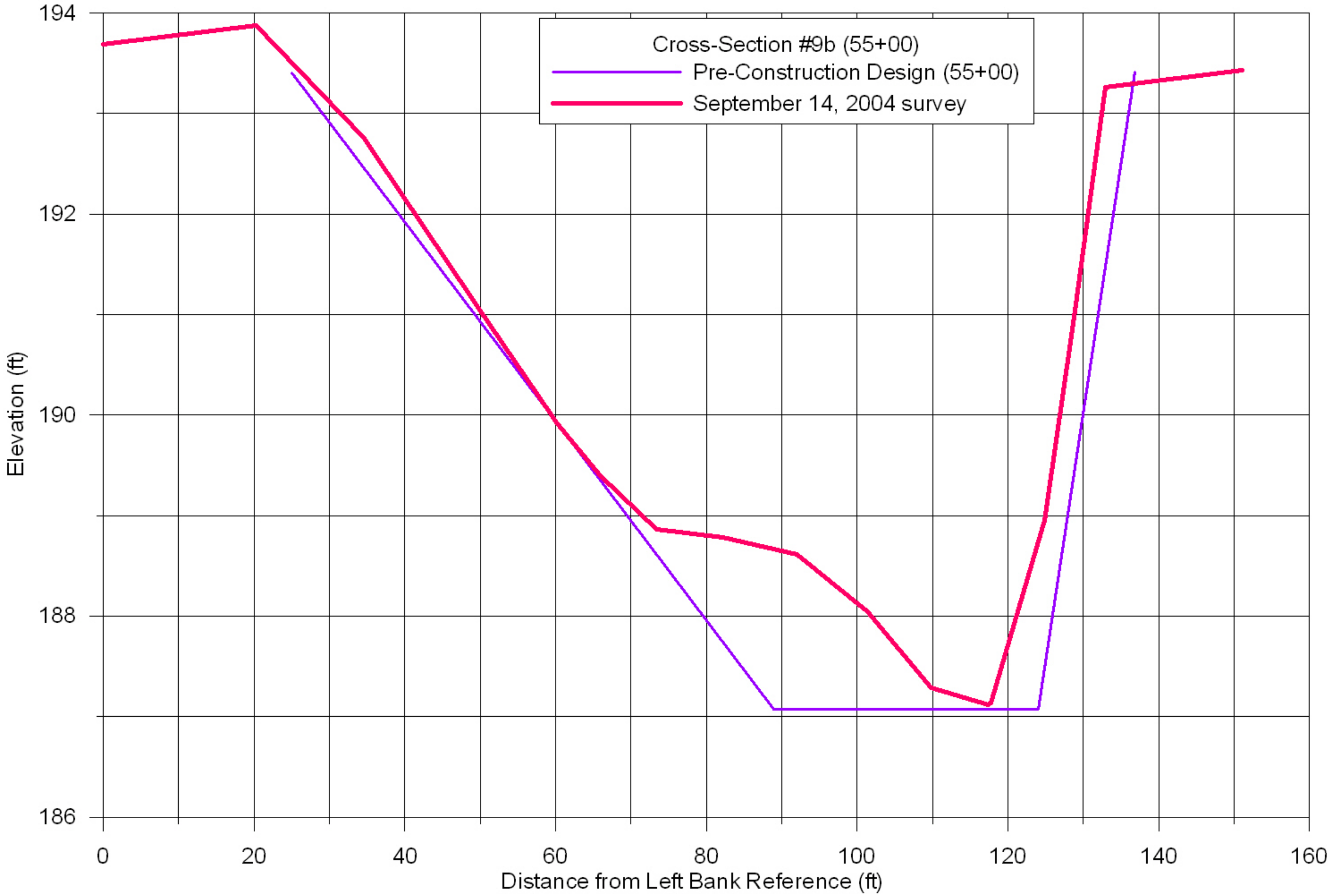


Figure 5.2.64. Cross-Section #9b Survey Profile

Figure 5.2.64

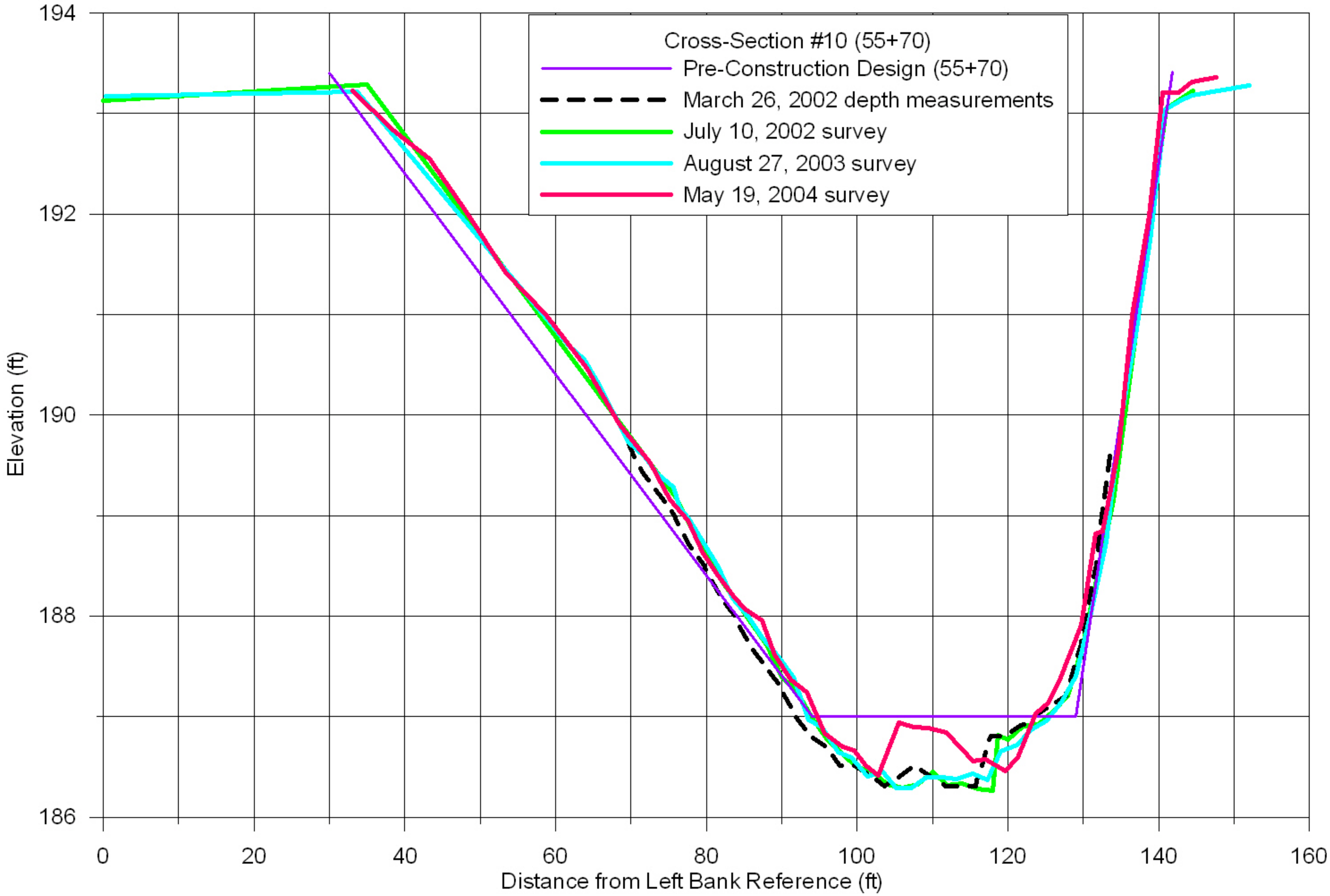


Figure 5.2.65. Cross-Section #10 Survey Profile

Figure 5.2.65

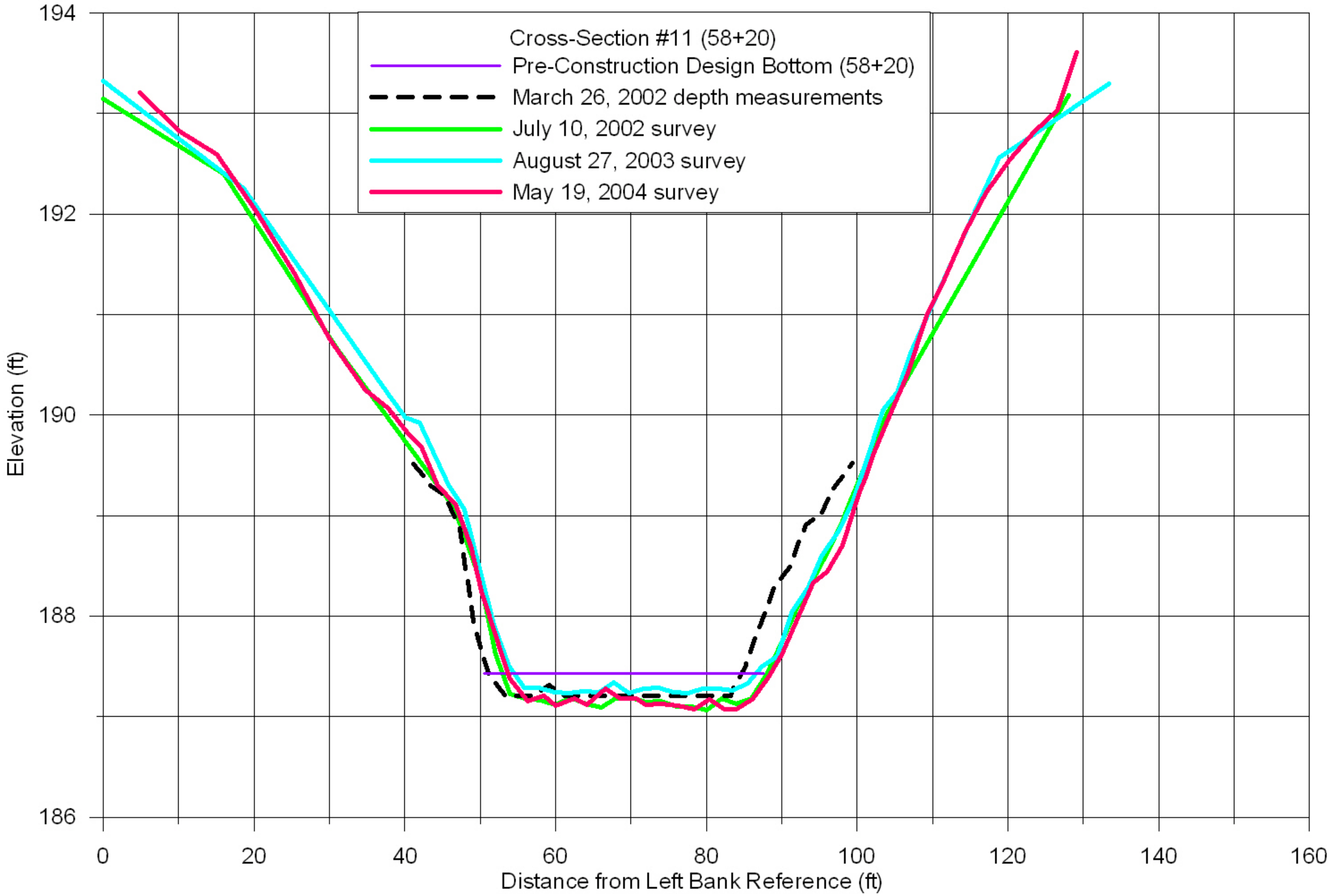


Figure 5.2.66. Cross-Section #11 Survey Profile

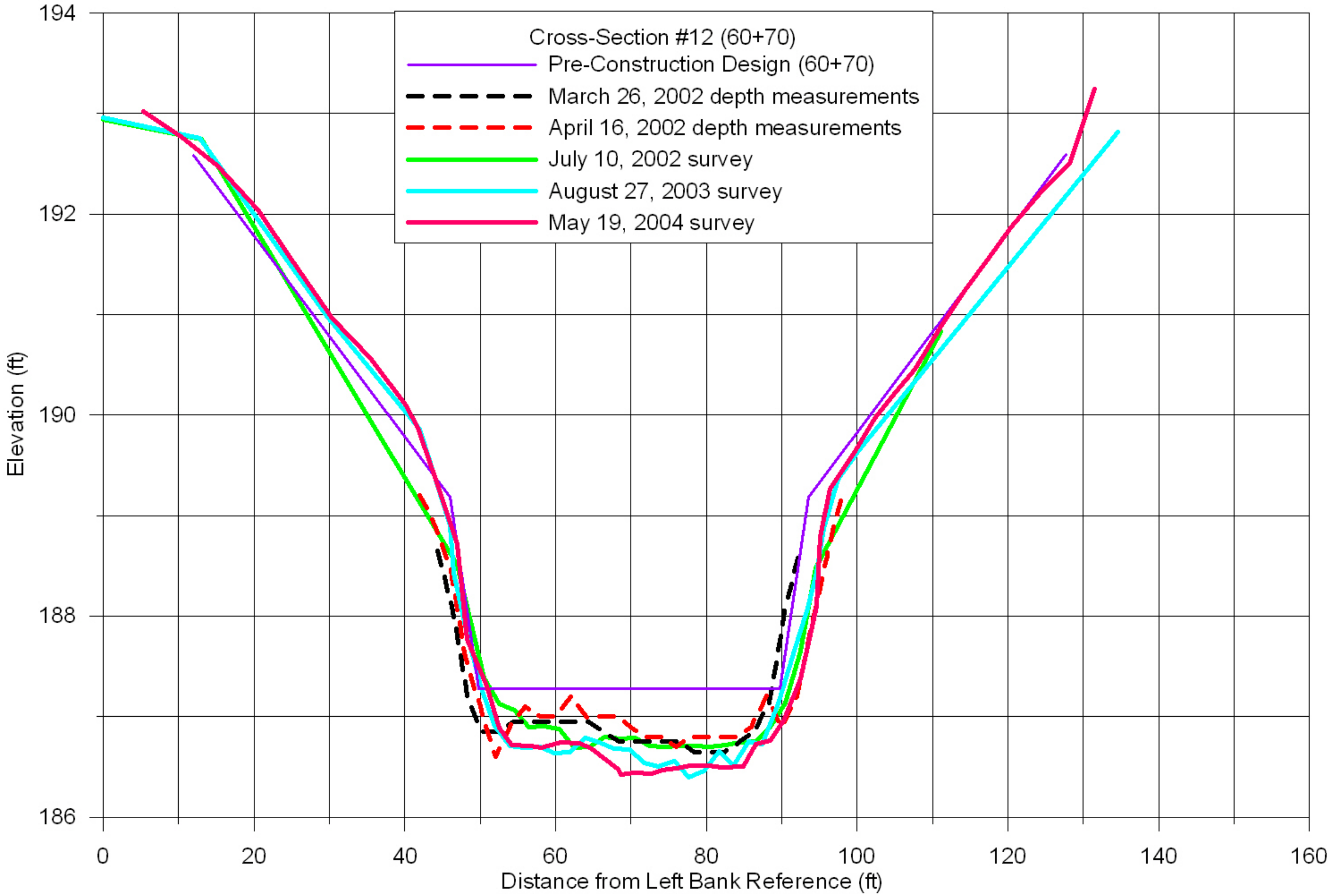


Figure 5.2.67. Cross-Section #12 Survey Profile

Figure 5.2.67

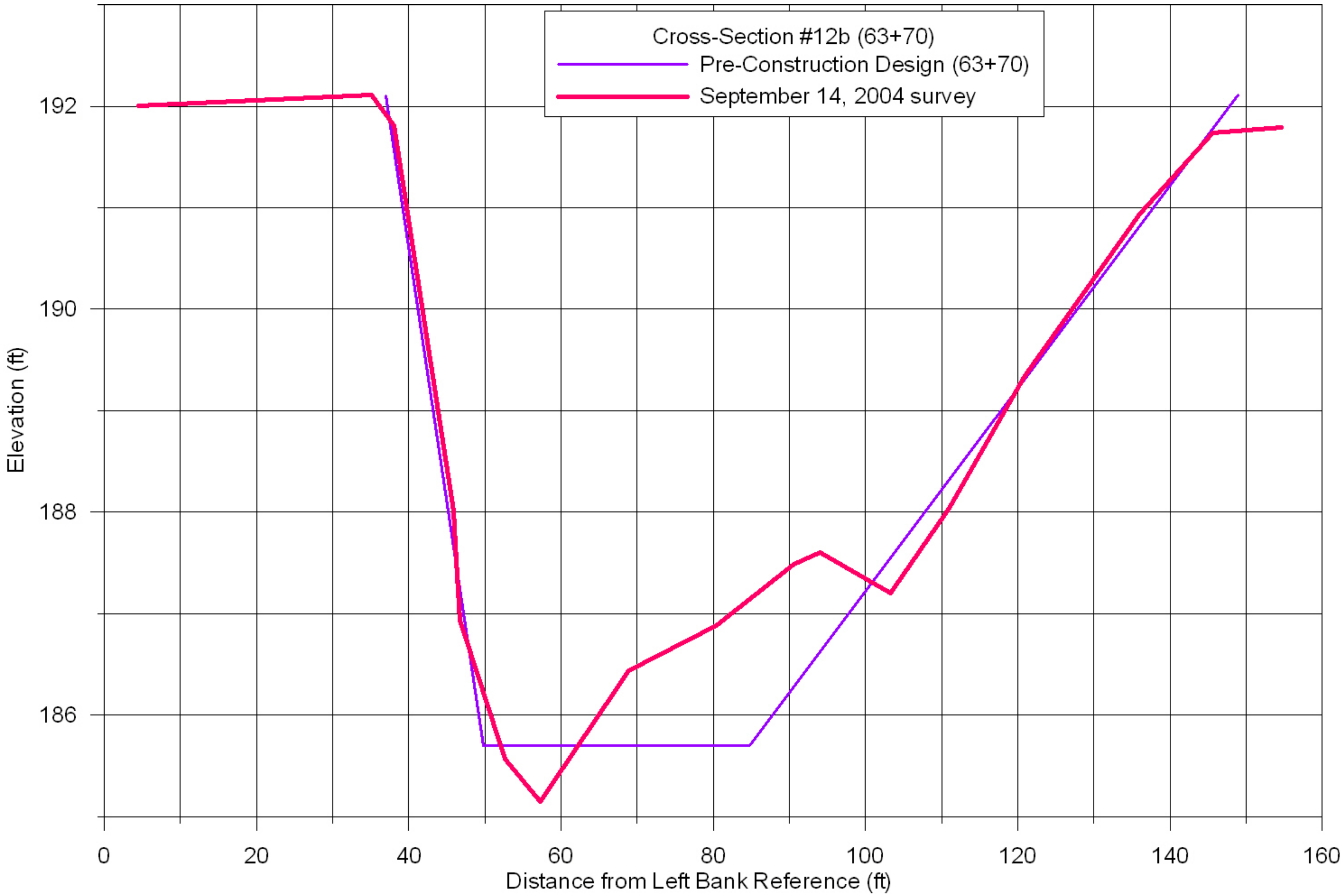


Figure 5.2.68. Cross-Section #12b Survey Profile

Figure 5.2.68

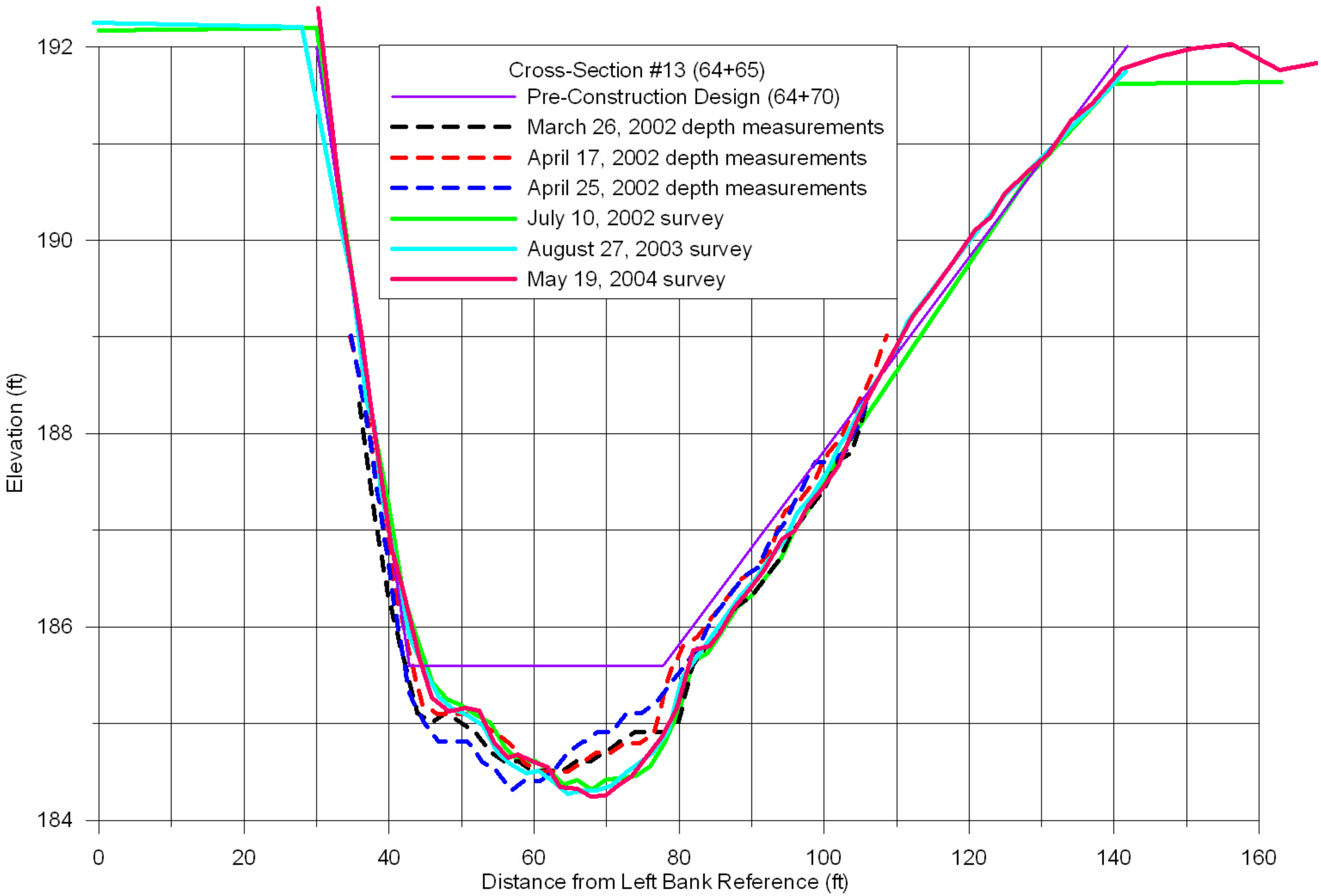


Figure 5.2.69. Cross-Section #13 Survey Profile

Figure 5.2.69

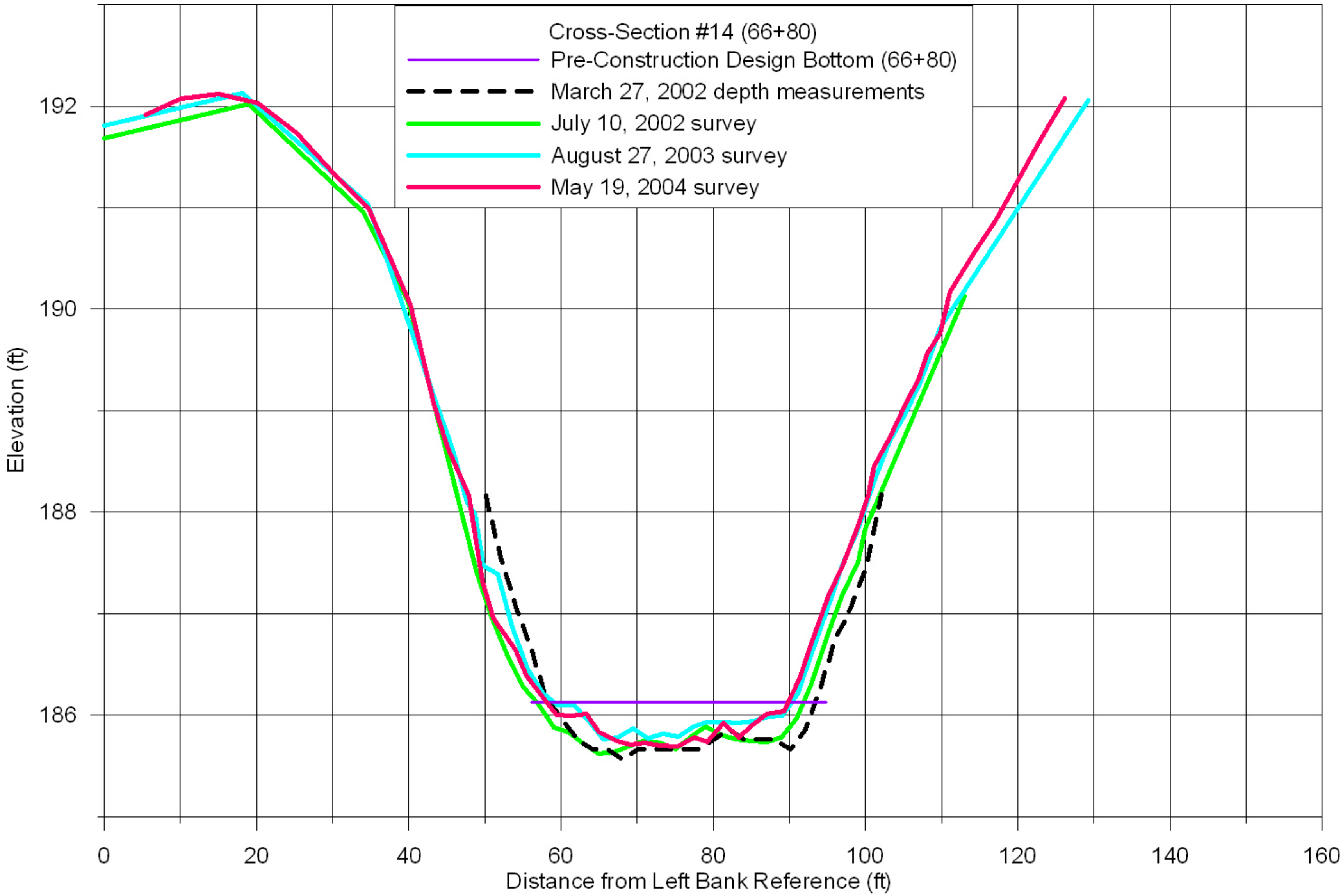


Figure 5.2.70. Cross-Section #14 Survey Profile

Figure 5.2.70

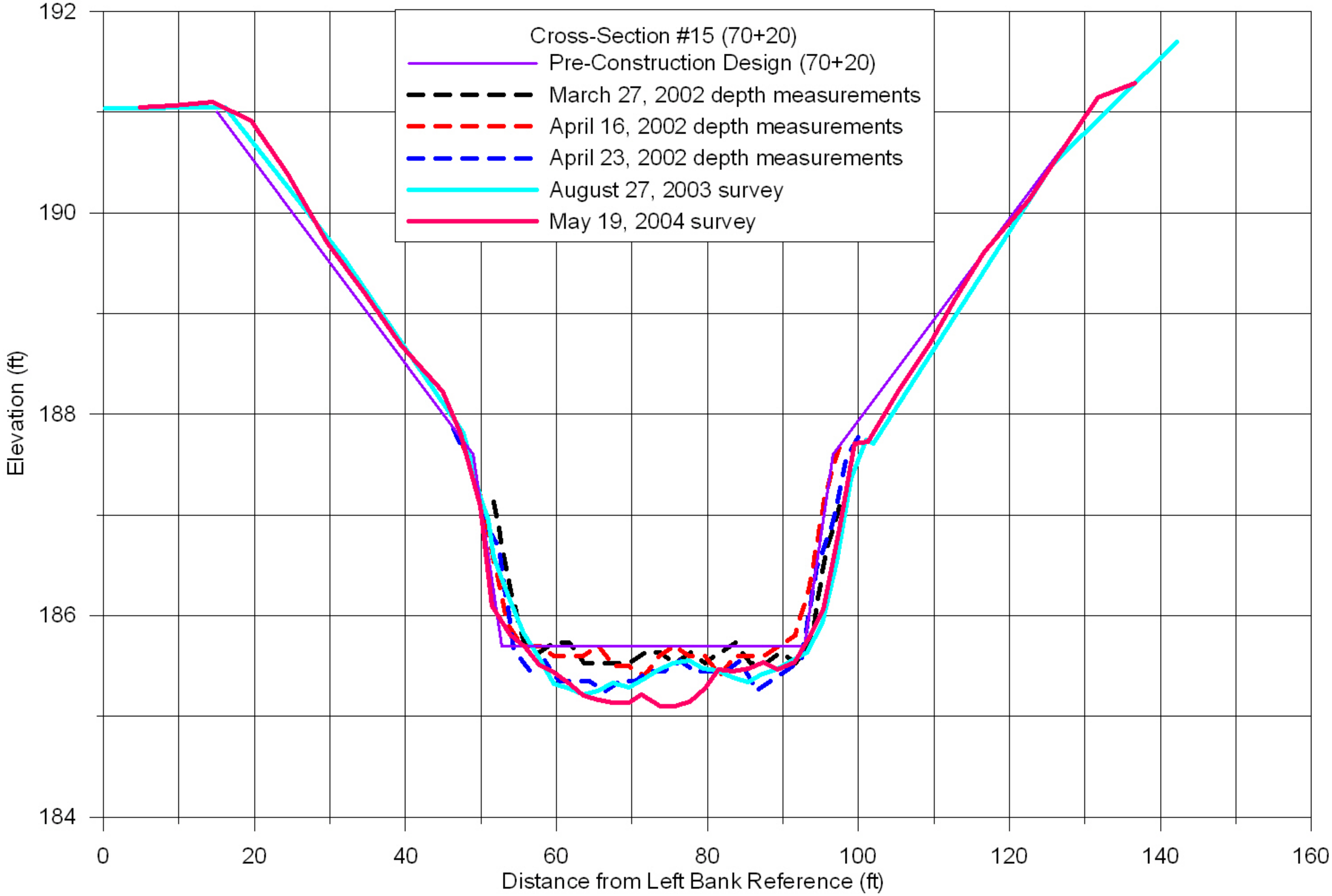


Figure 5.2.71. Cross-Section #15 Survey Profile

Figure 5.2.71

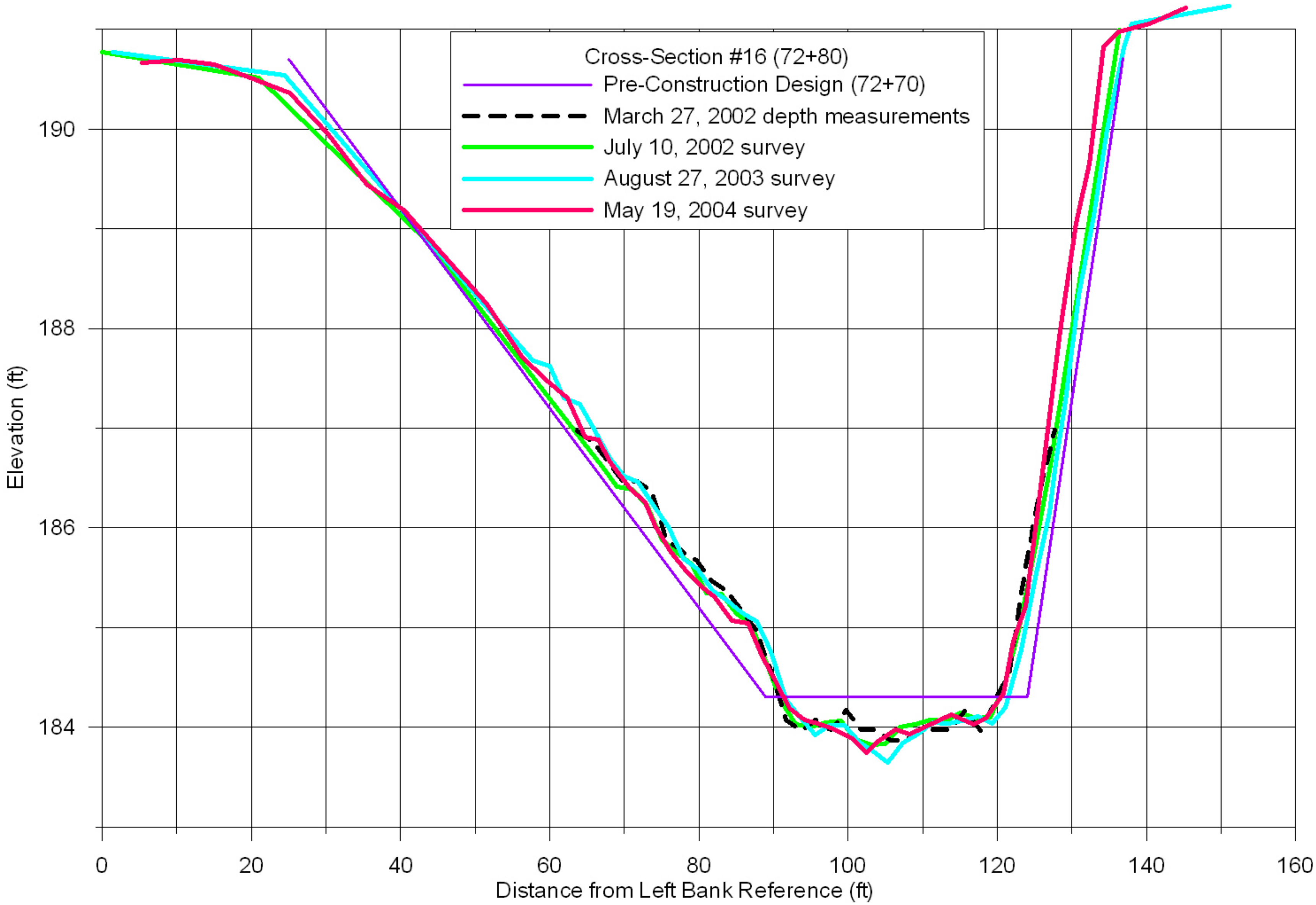


Figure 5.2.72. Cross-Section #16 Survey Profile

Figure 5.2.72

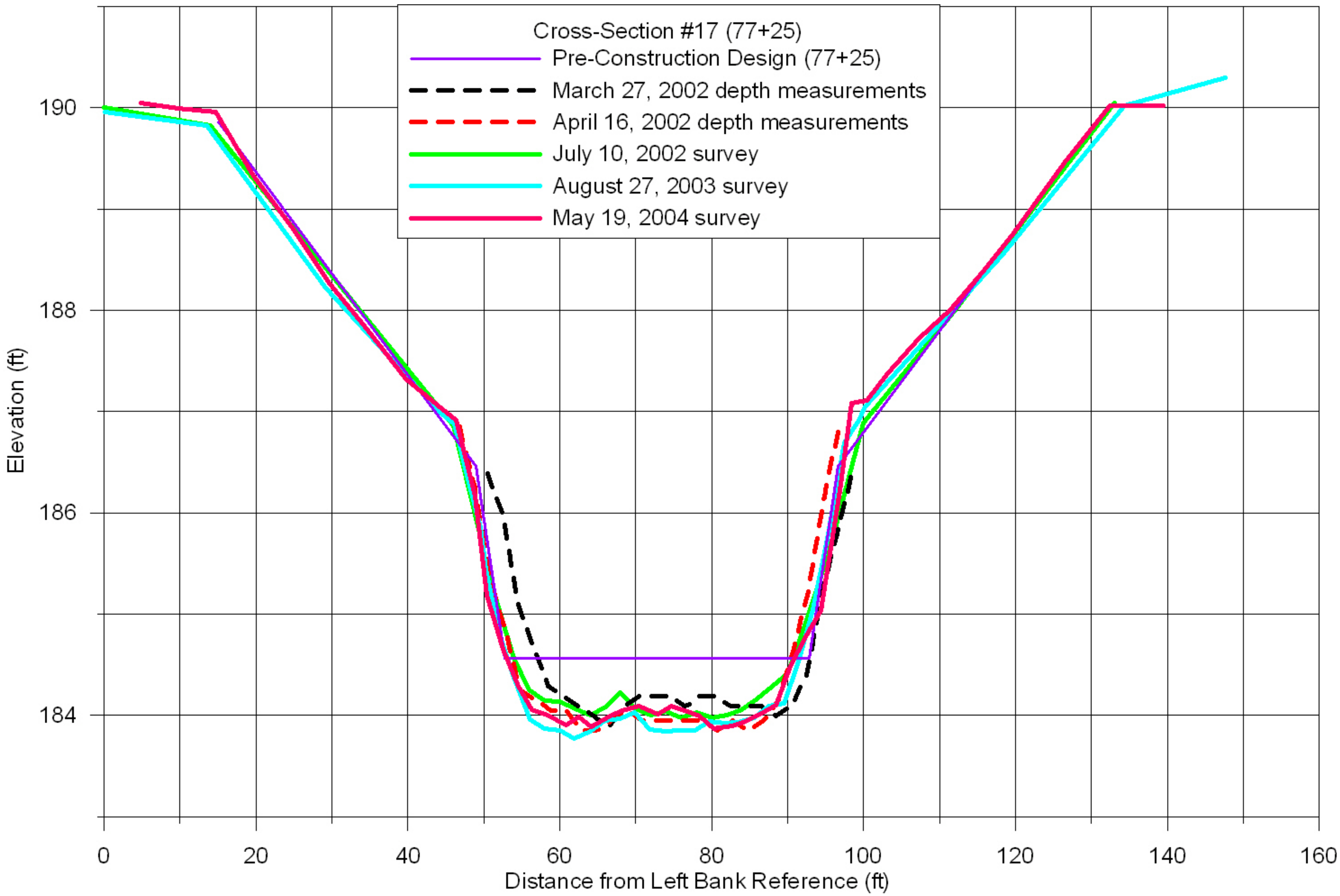


Figure 5.2.73. Cross-Section #17 Survey Profile

Figure 5.2.73

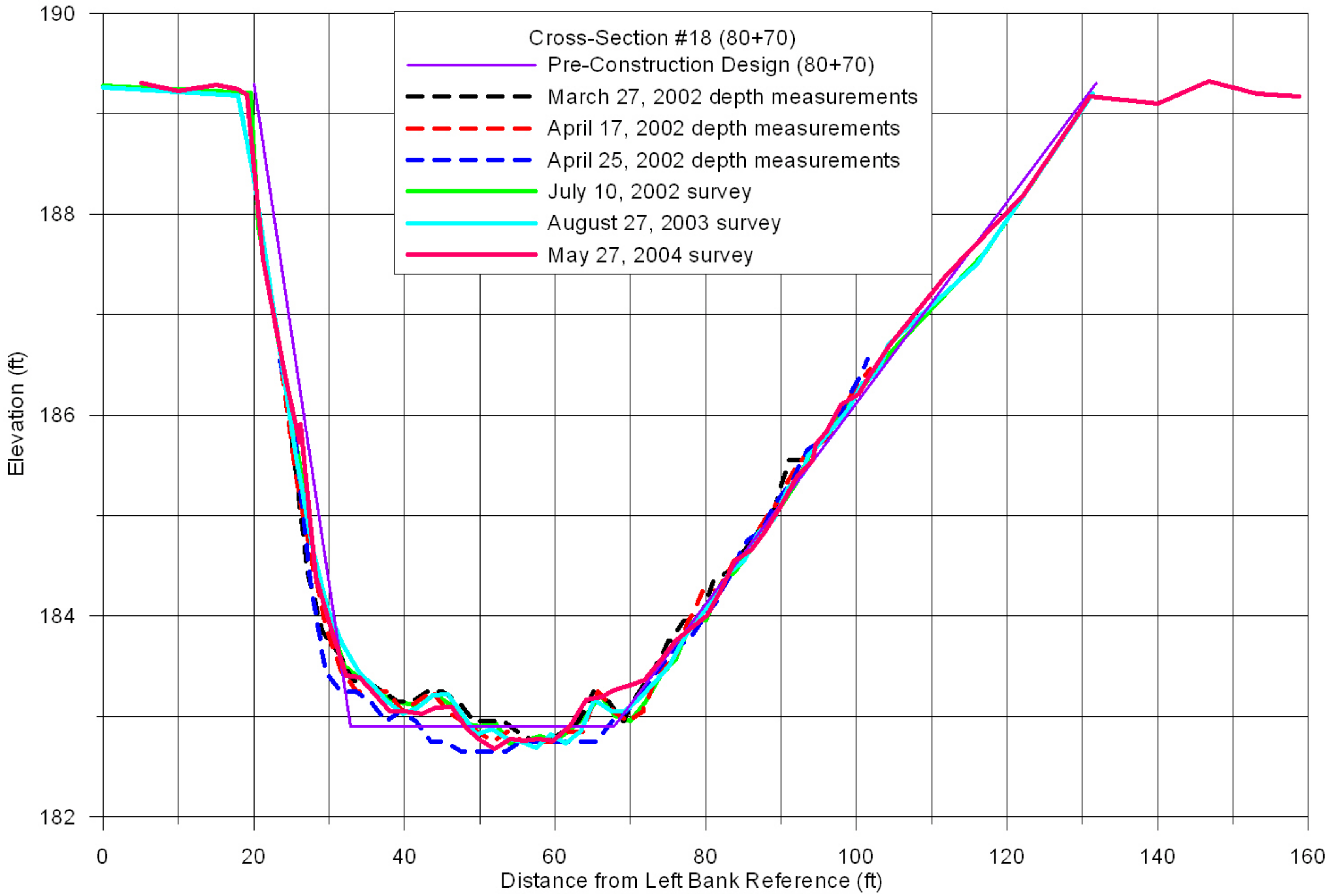


Figure 5.2.74. Cross-Section #18 Survey Profile

Figure 5.2.74

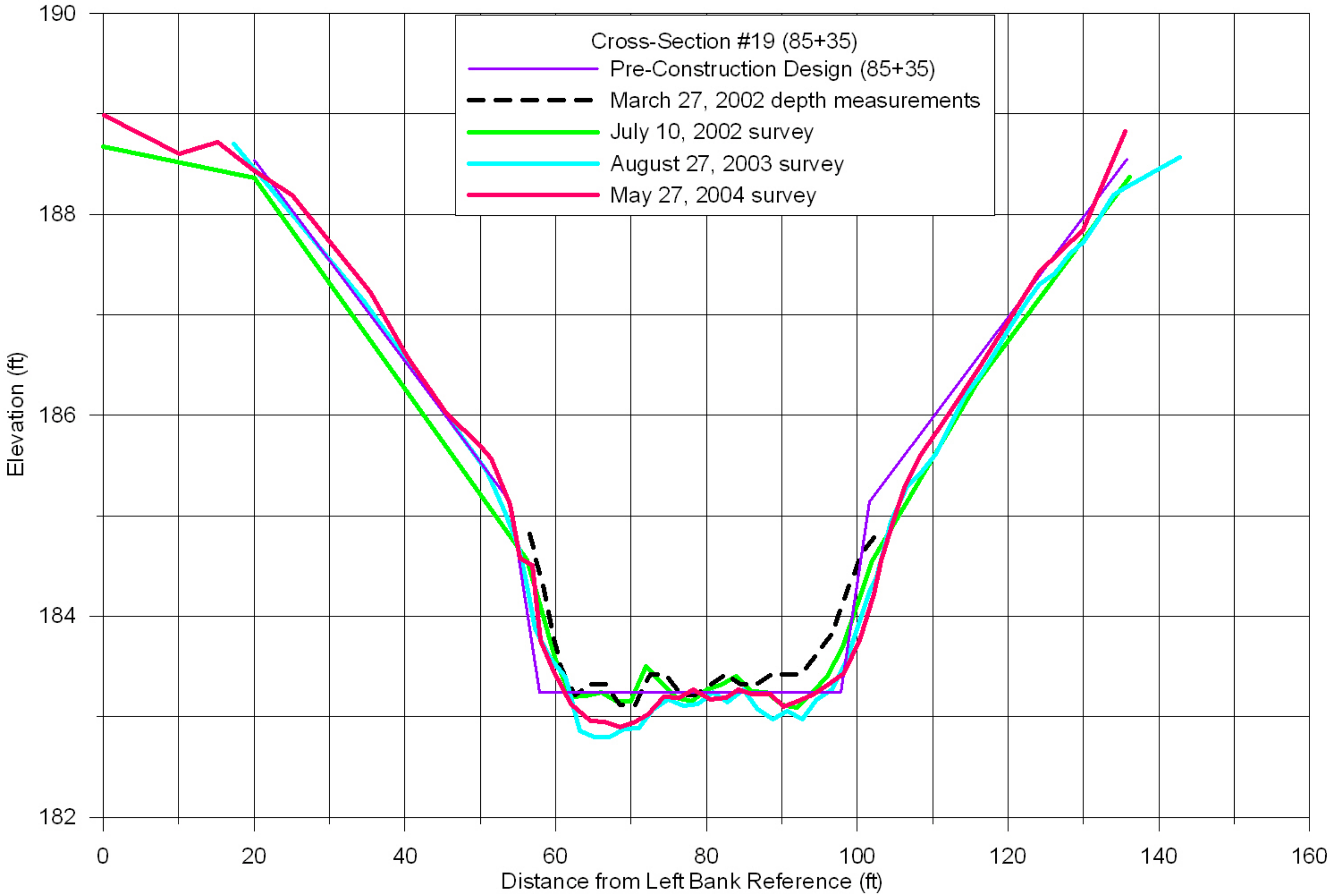


Figure 5.2.75. Cross-Section #19 Survey Profile

Figure 5.2.75

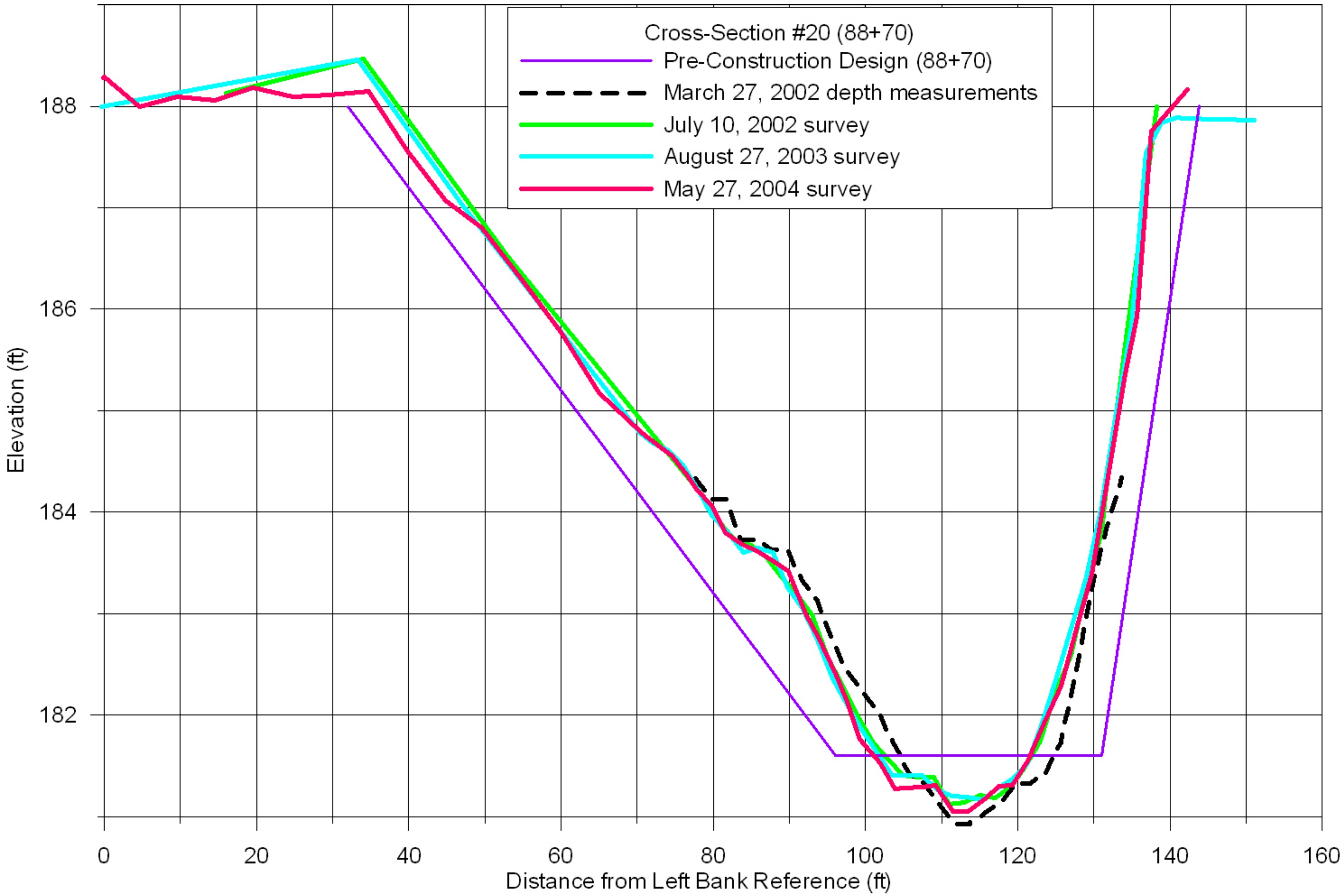


Figure 5.2.76. Cross-Section #20 Survey Profile

Figure 5.2.76

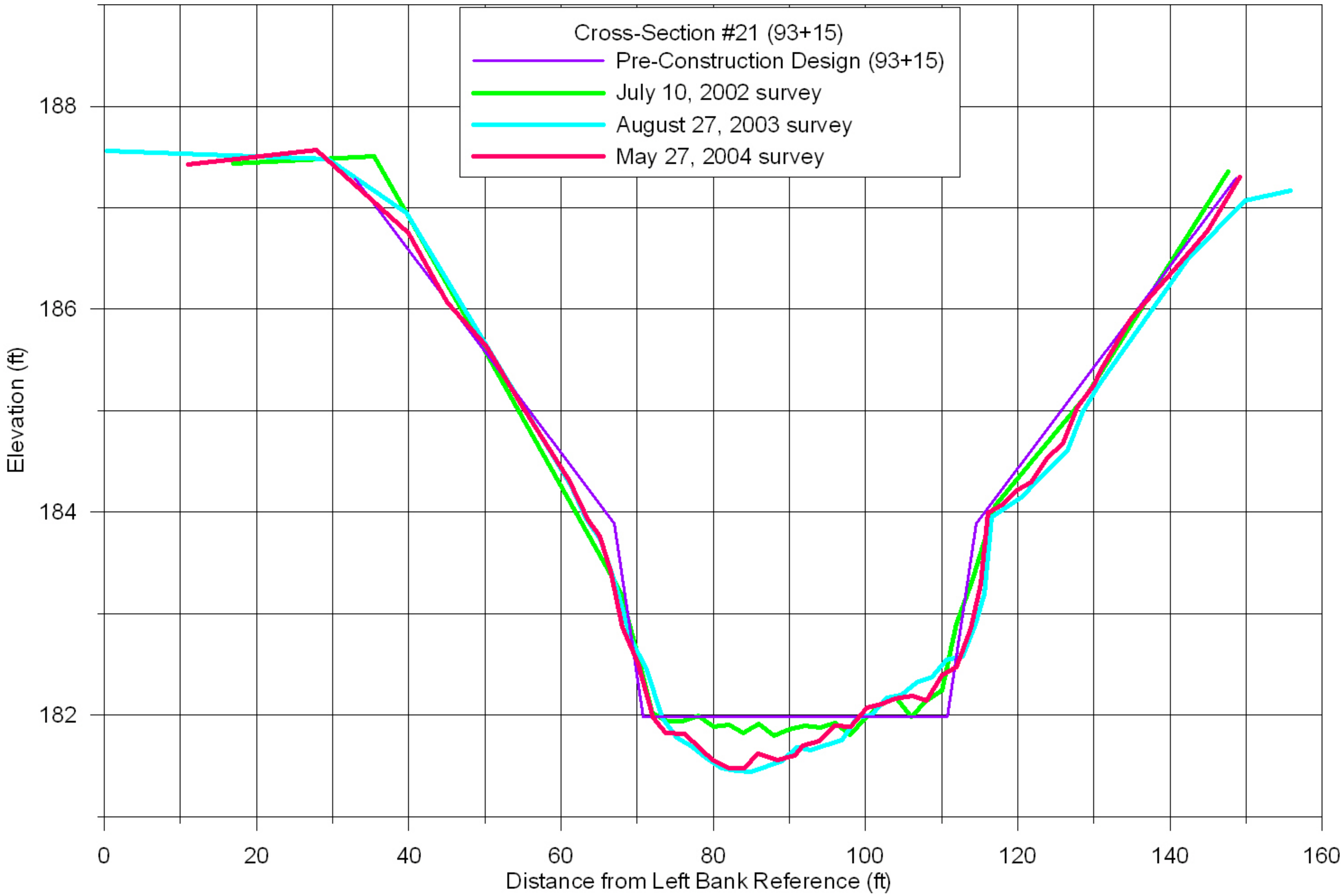


Figure 5.2.77. Cross-Section #21 Survey Profile

Figure 5.2.77

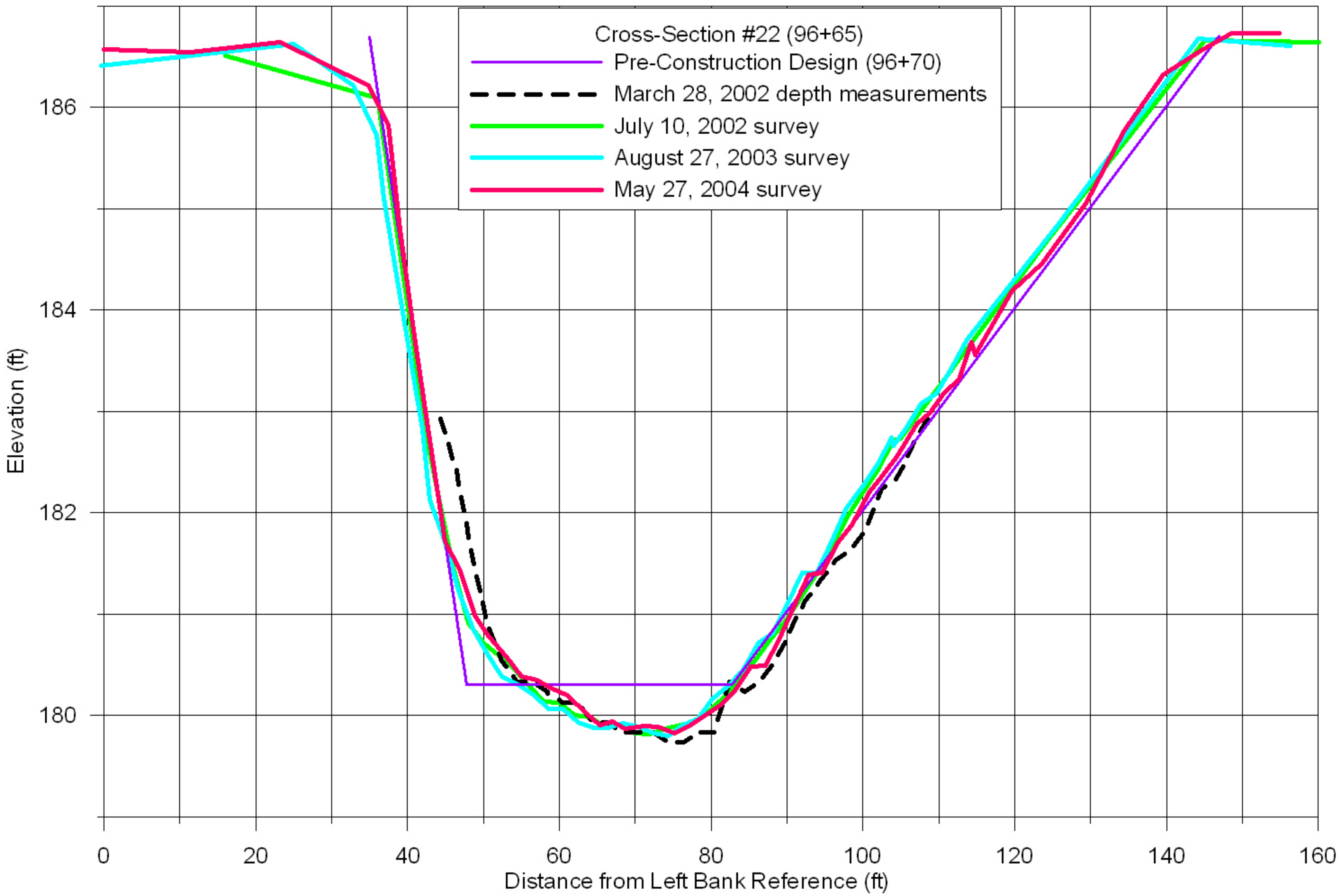


Figure 5.2.78. Cross-Section #22 Survey Profile

Figure 5.2.78

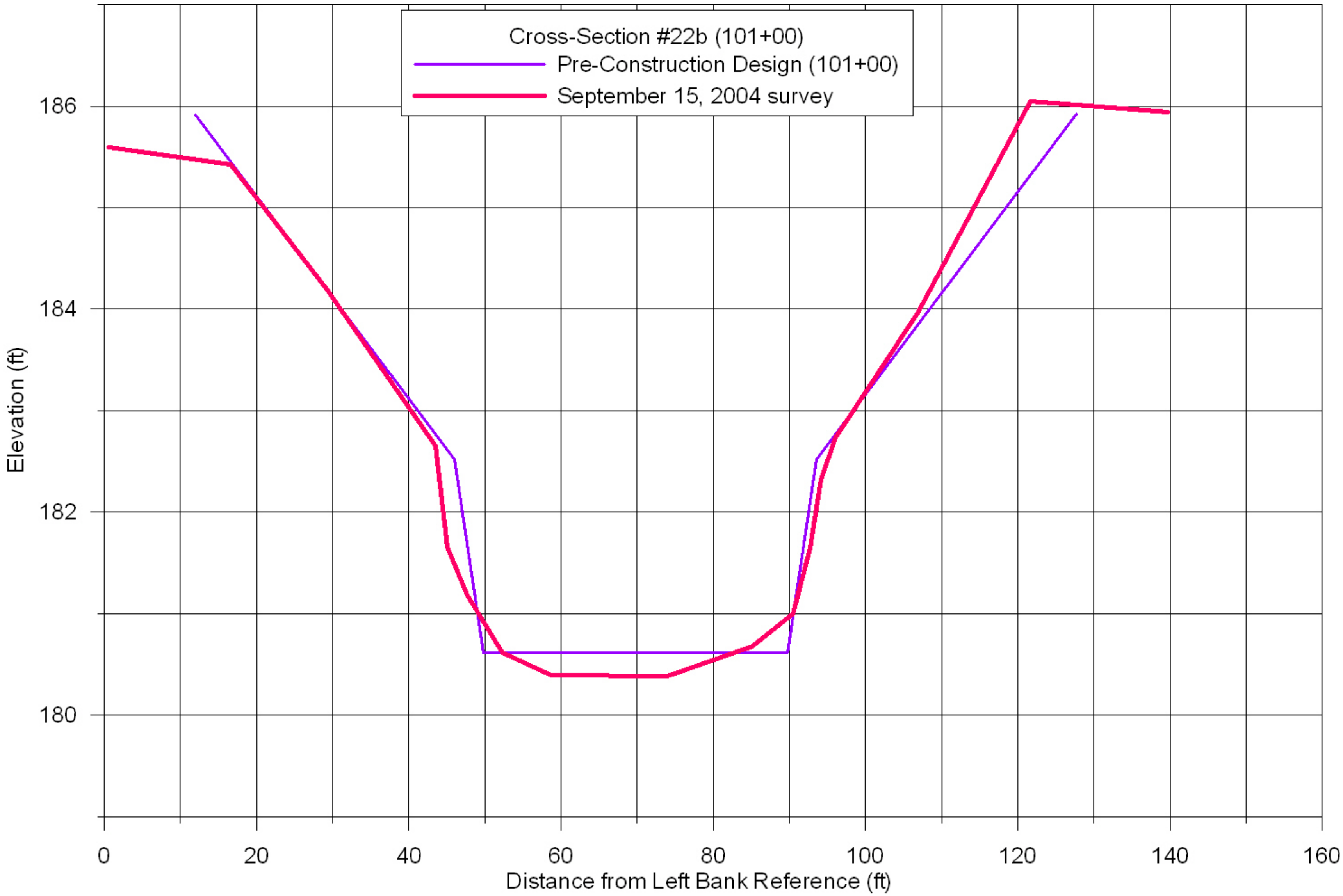


Figure 5.2.79. Cross-Section #22b Survey Profile

Figure 5.2.79

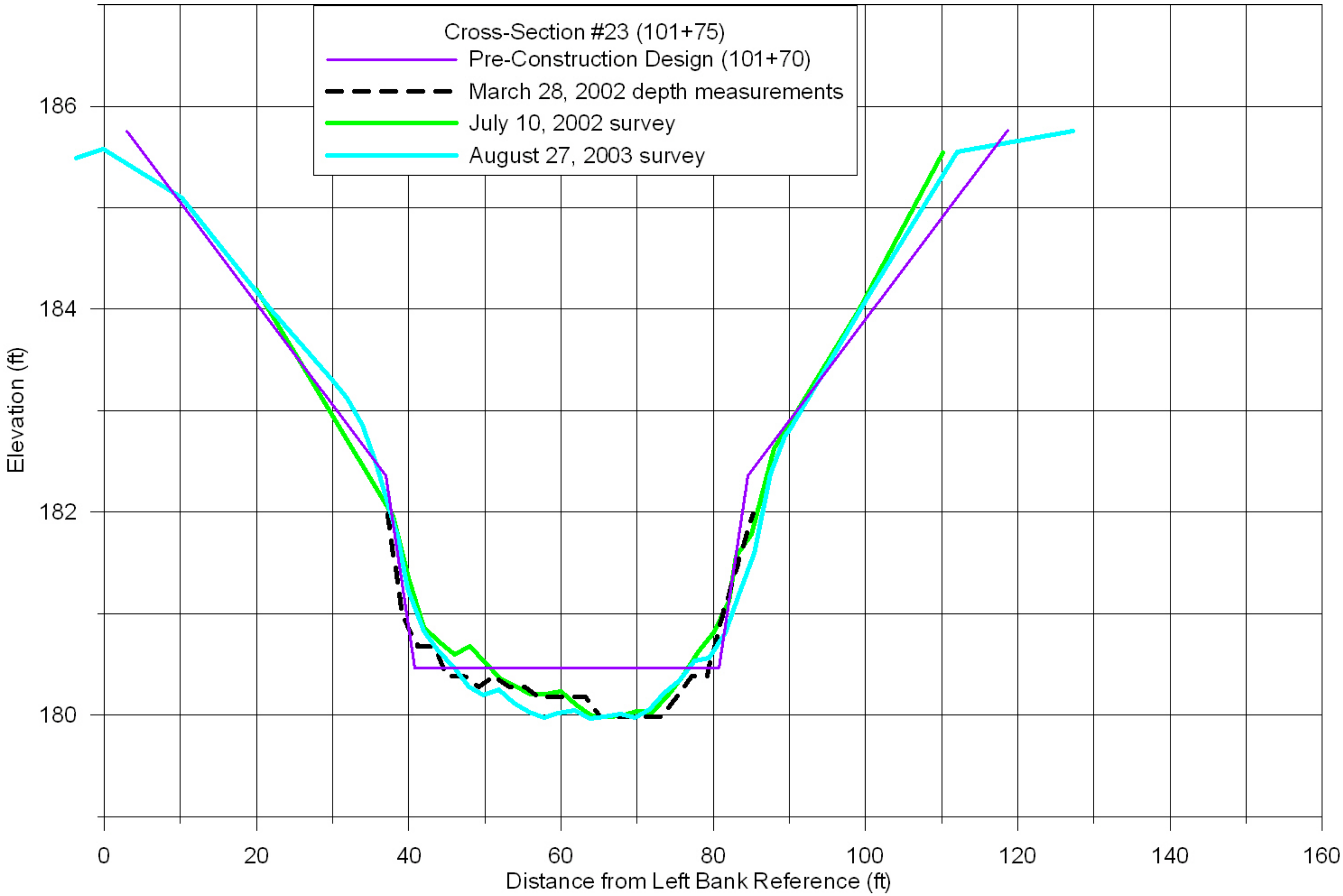


Figure 5.2.80. Cross-Section #23 Survey Profile

Figure 5.2.80

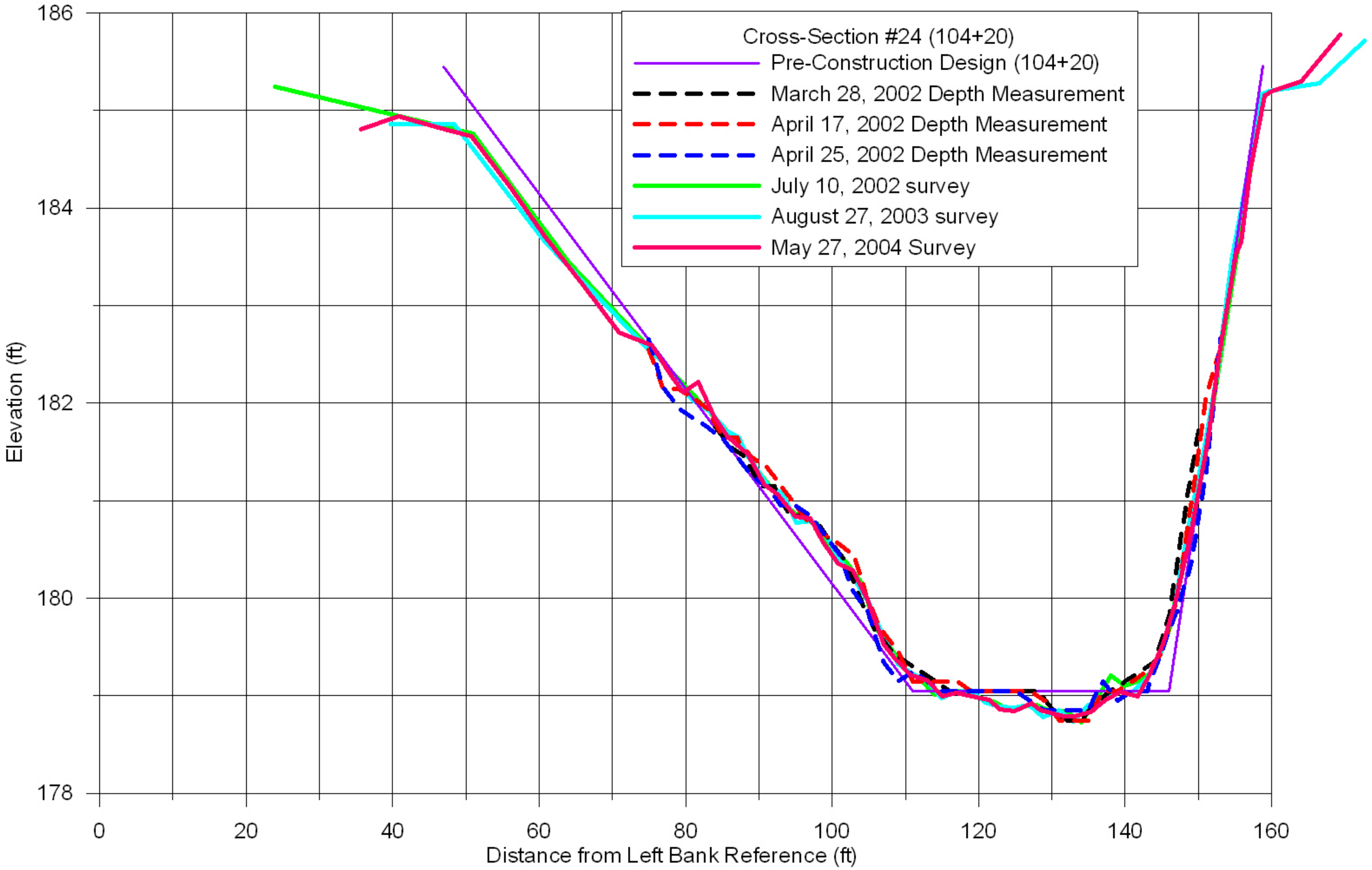


Figure 5.2.81. Cross-Section #24 Survey Profile

Figure 5.2.81

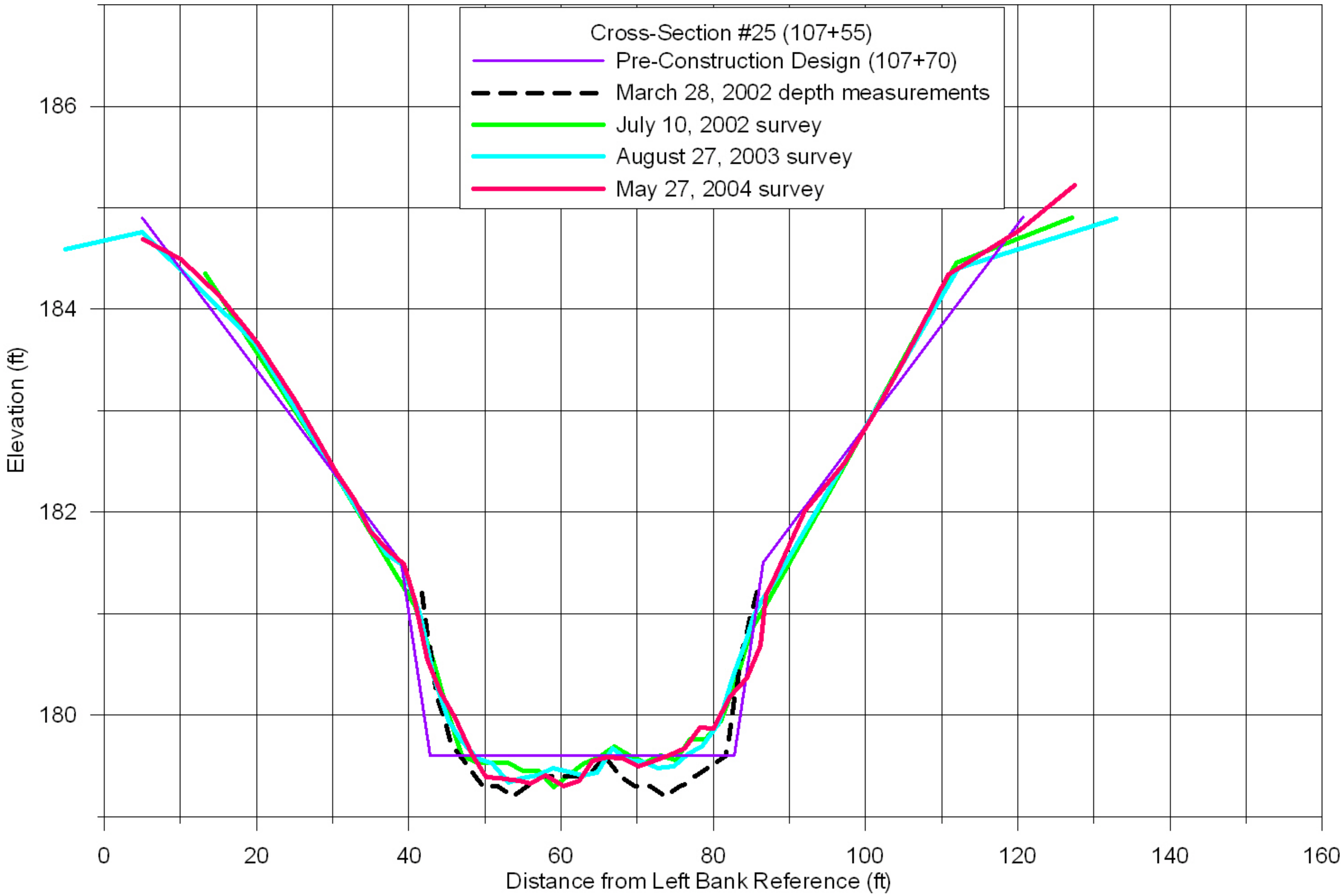


Figure 5.2.82. Cross-Section #25 Survey Profile

Figure 5.2.82

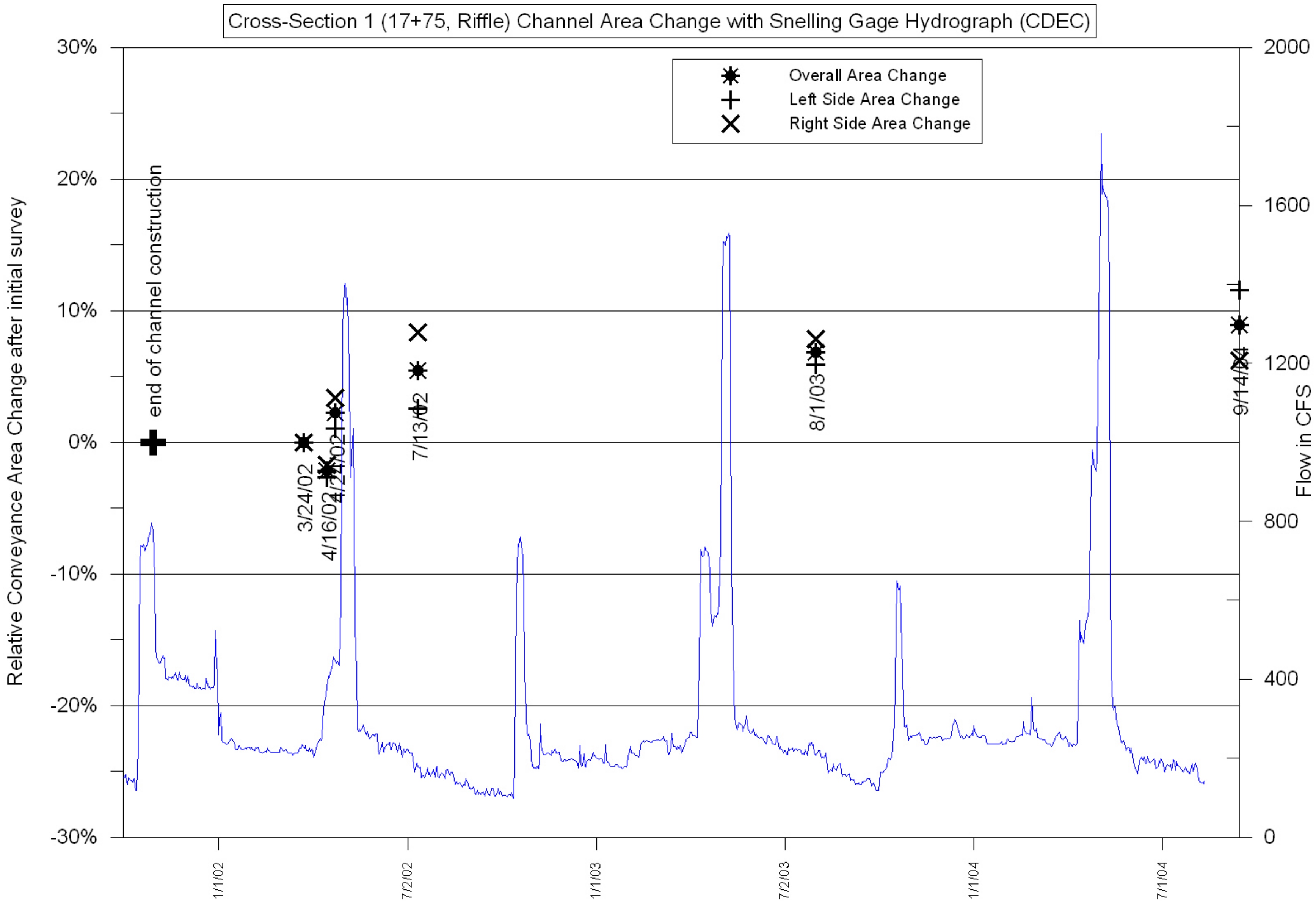


Figure 5.2.83. Cross-Section 1 Relative Conveyance Area Changes

Figure 5.2.83

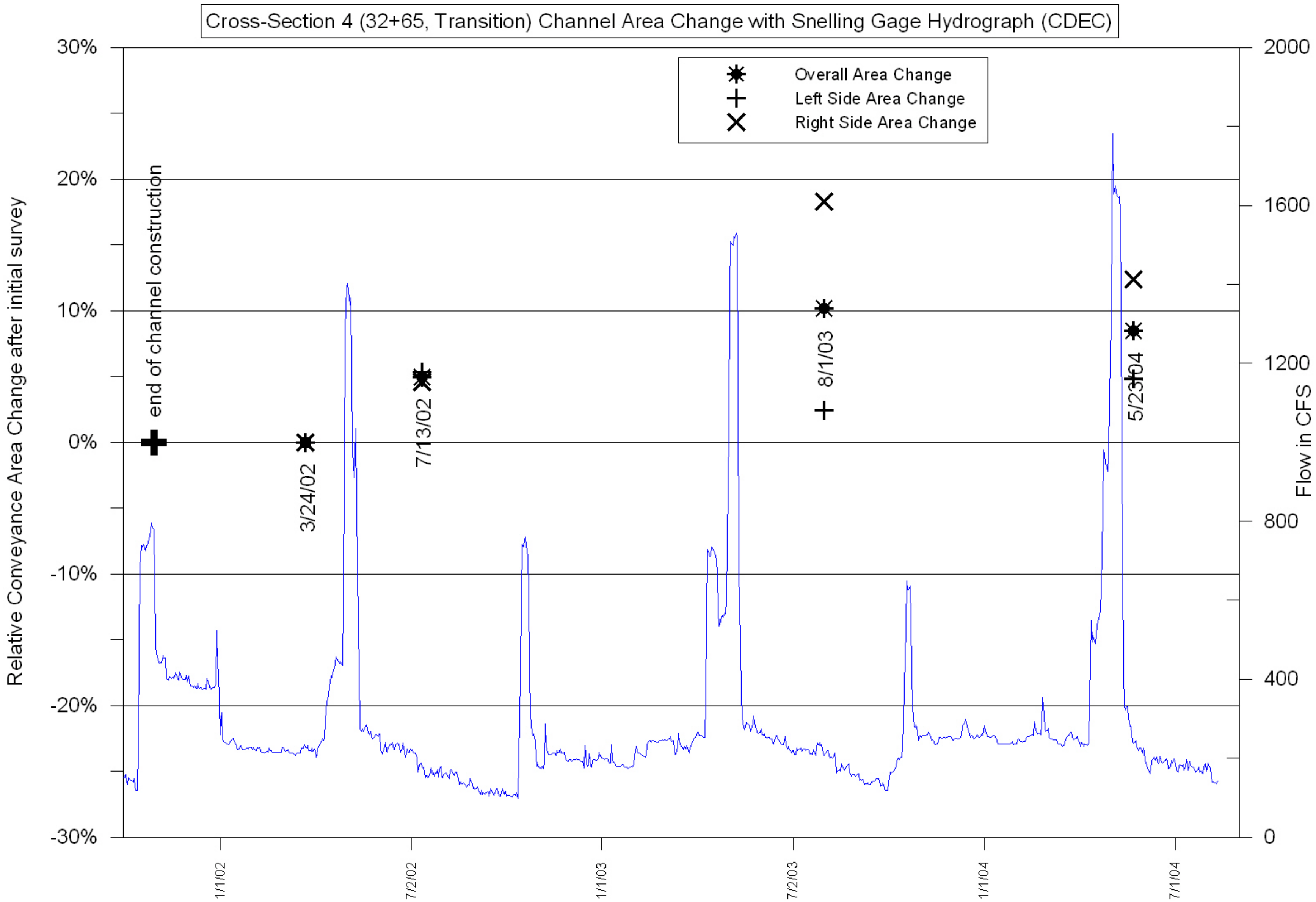


Figure 5.2.84. Cross-Section 4 Relative Conveyance Area Changes

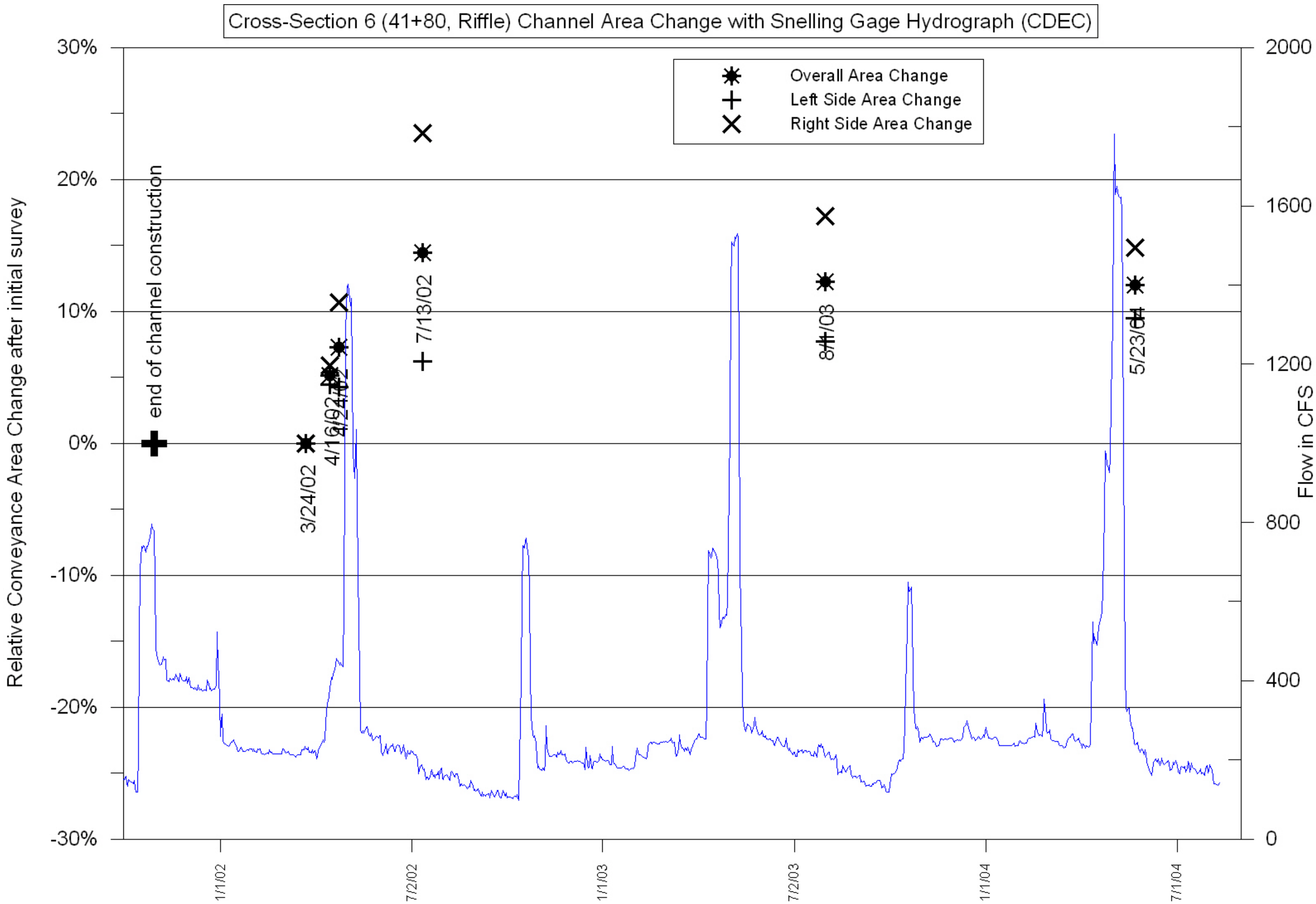


Figure 5.2.85. Cross-Section 6 Relative Conveyance Area Changes

Figure 5.2.85

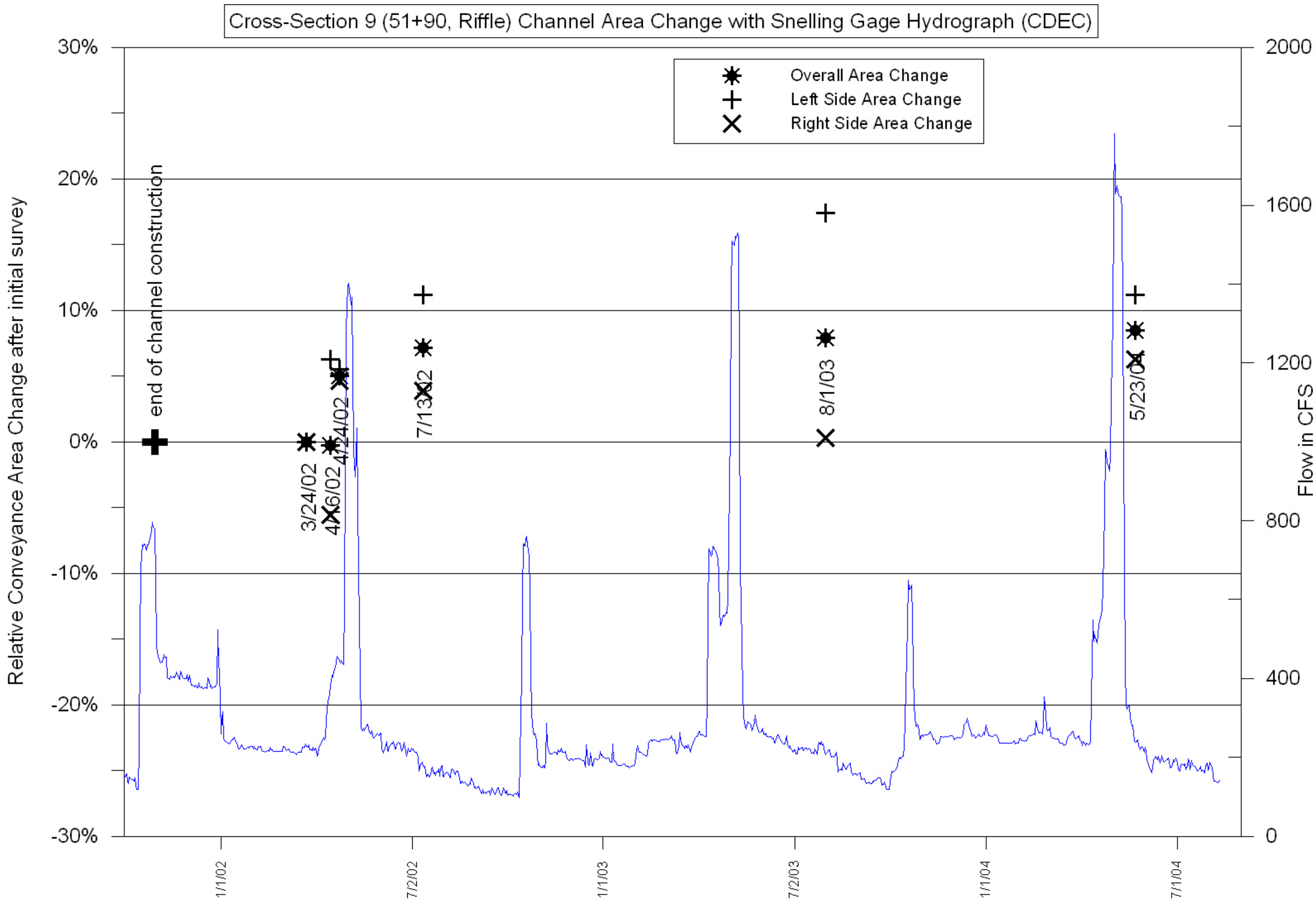


Figure 5.2.86. Cross-Section 9 Relative Conveyance Area Changes

Figure 5.2.86

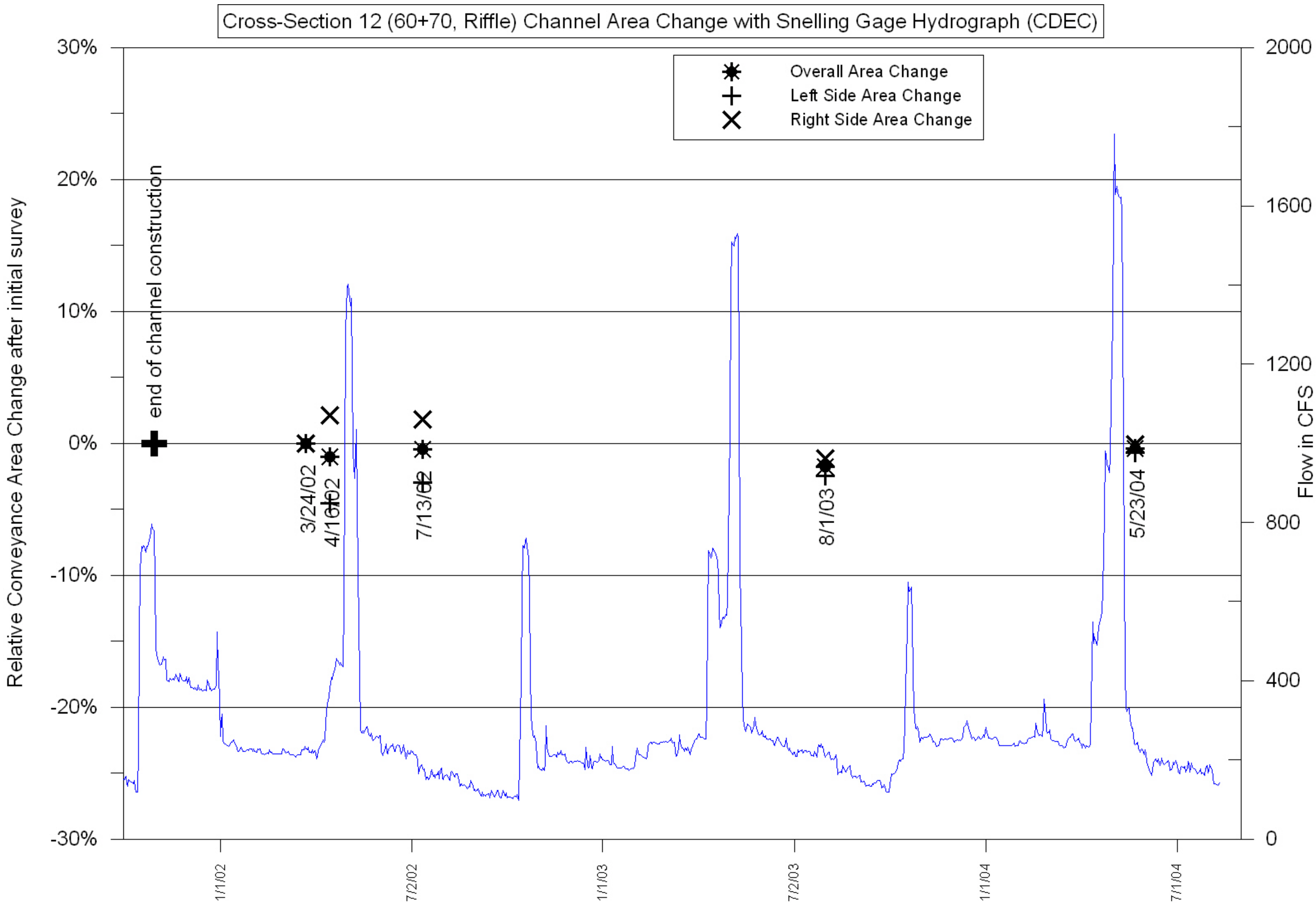


Figure 5.2.87. Cross-Section 12 Relative Conveyance Area Changes

Figure 5.2.87

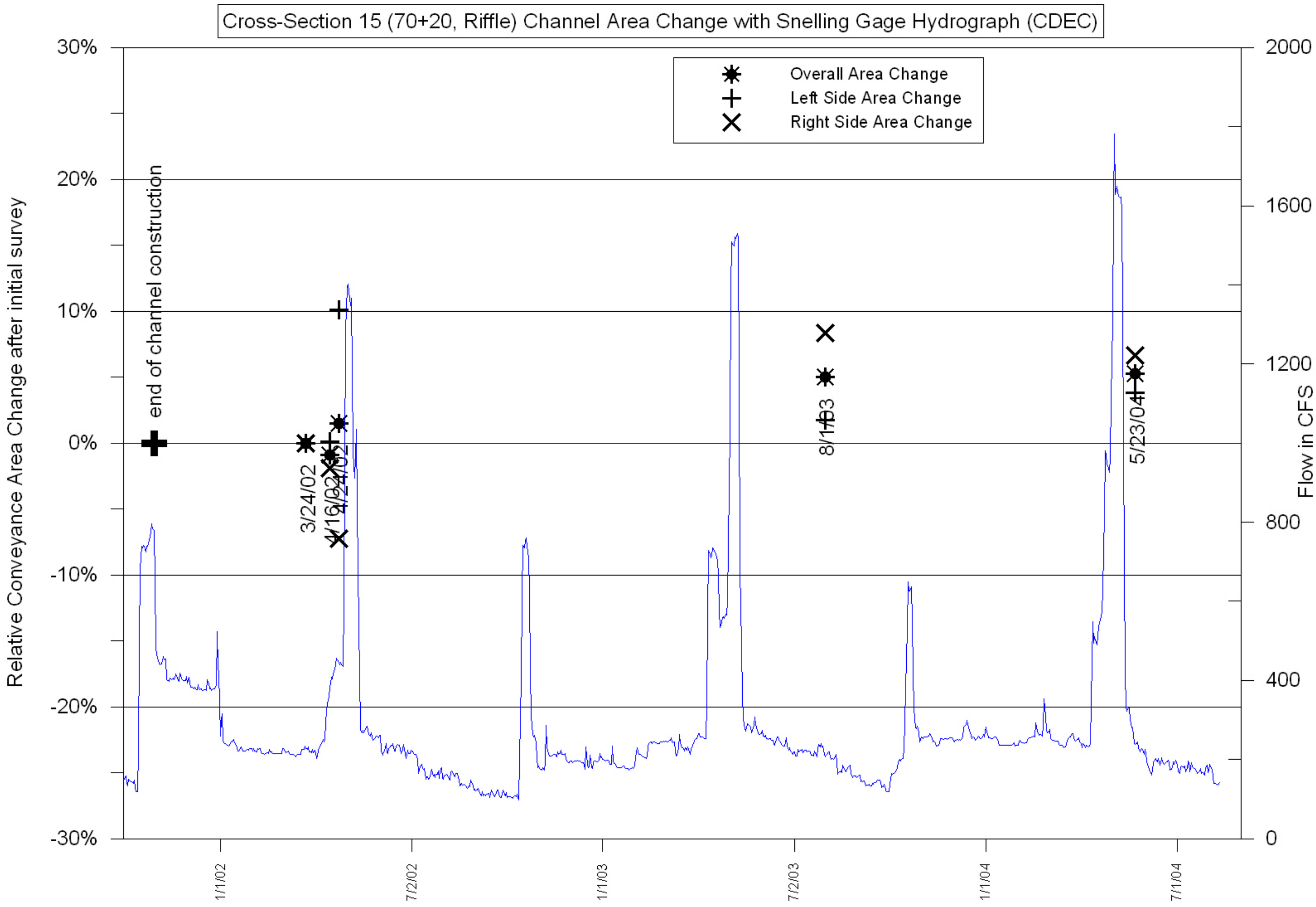


Figure 5.2.88. Cross-Section 15 Relative Conveyance Area Changes

Figure 5.2.88

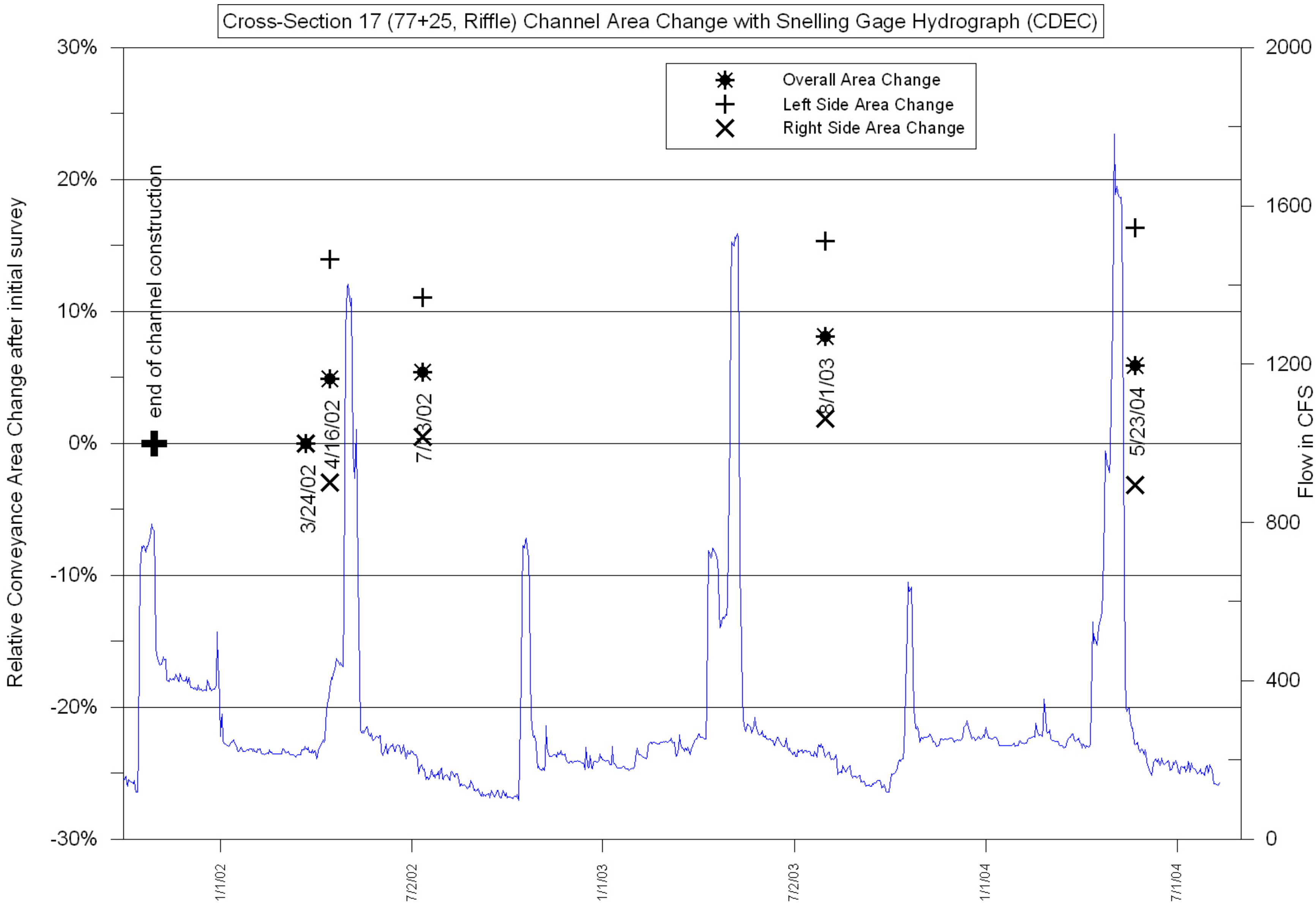


Figure 5.2.89. Cross-Section 17 Relative Conveyance Area Changes

Figure 5.2.89

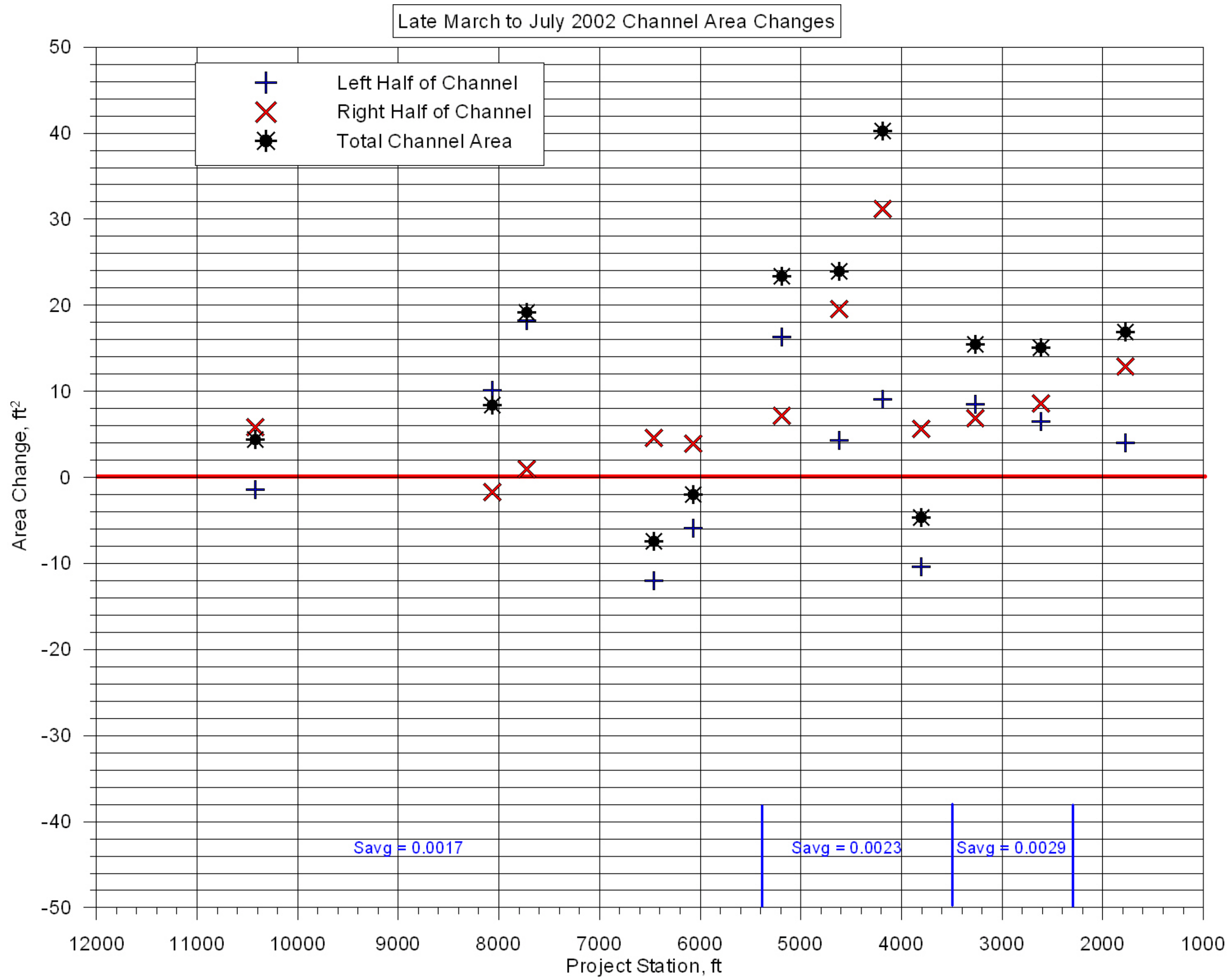


Figure 5.2.90. Total Conveyance Area Changes by Station, March to July 2002 (Reach Channel Slopes in Blue)

Figure 5.2.90

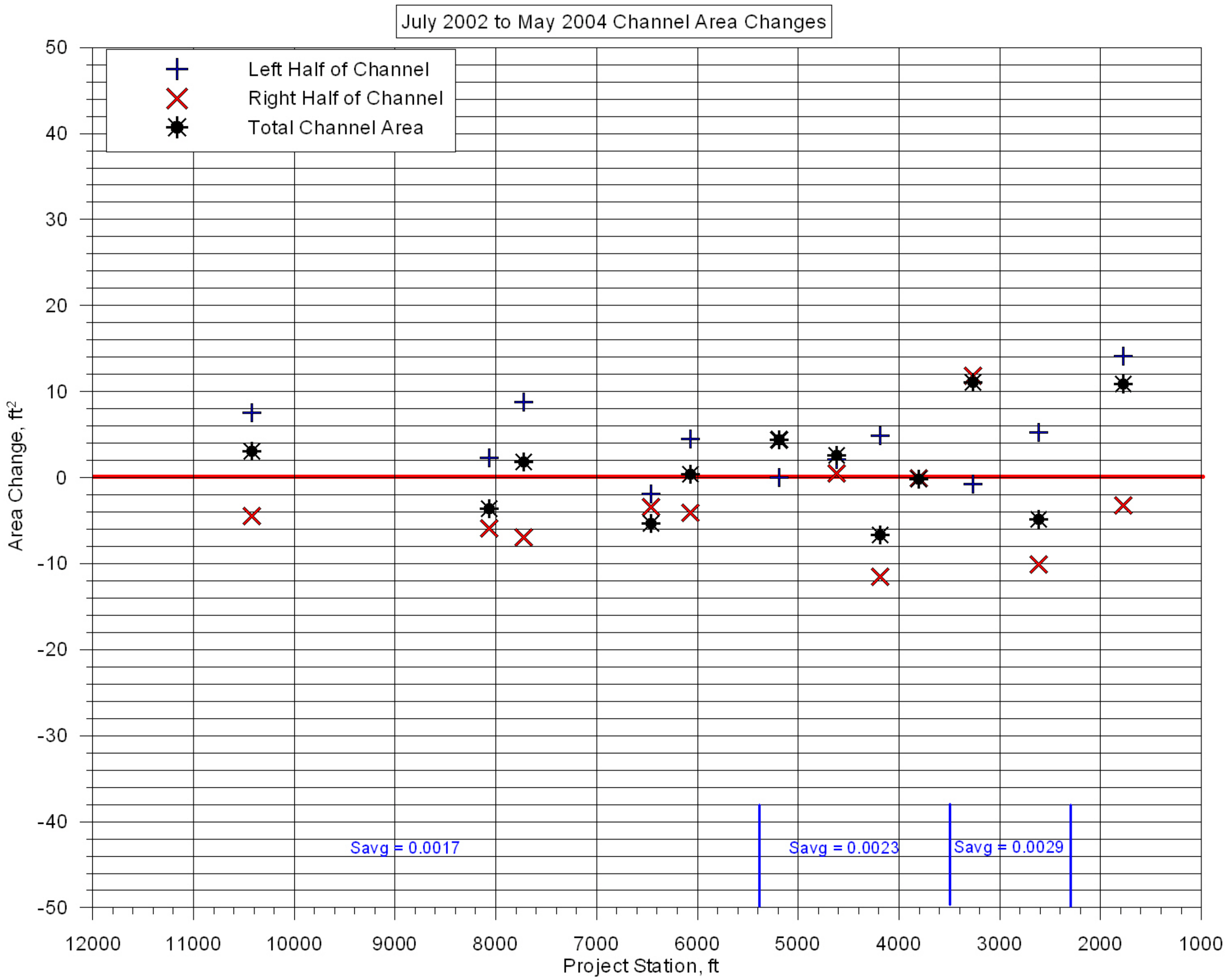


Figure 5.2.91. Total Conveyance Area Changes by Station, July 2002 to May 2004 (Reach Channel Slopes in Blue)

Figure 5.2.91

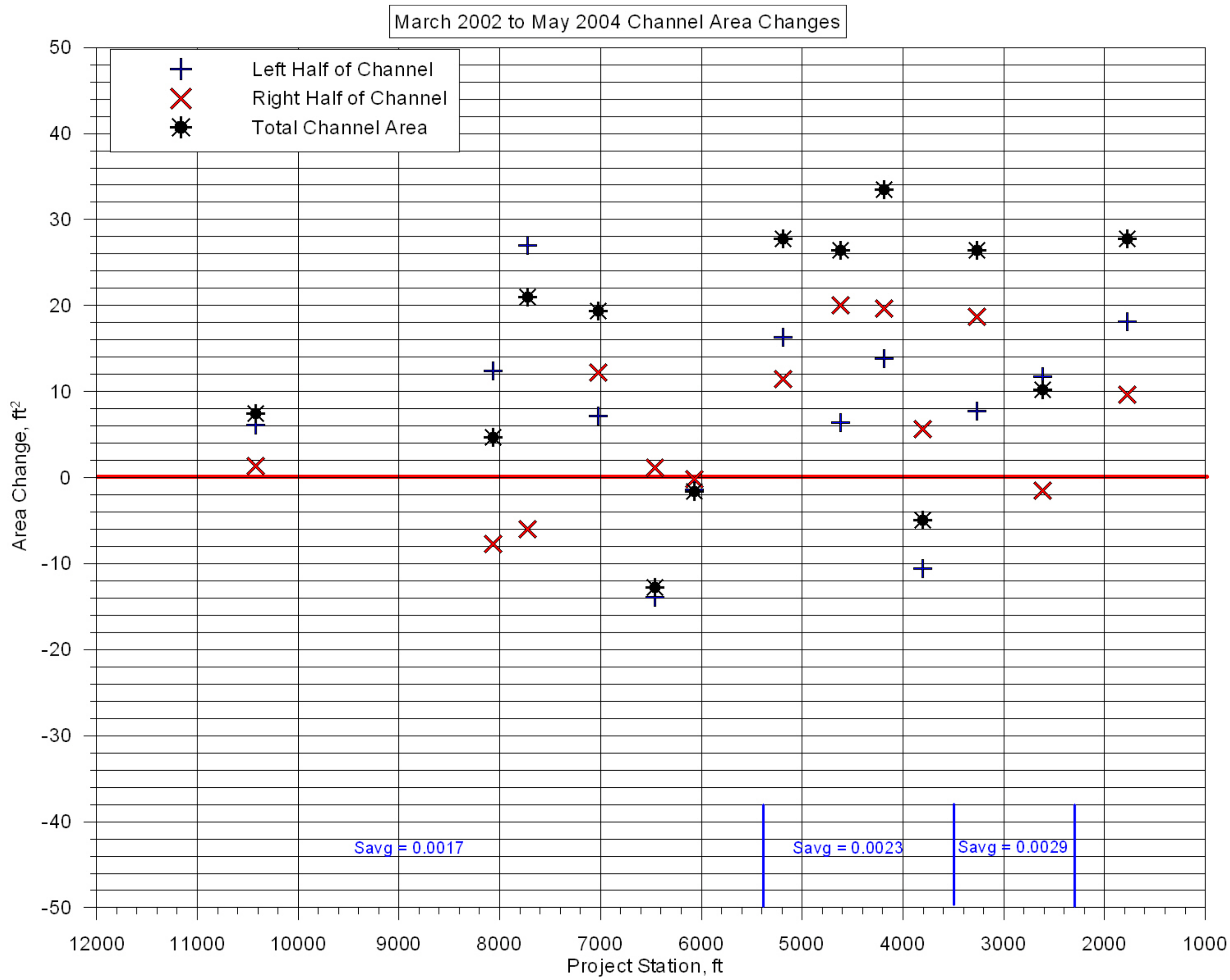


Figure 5.2.92. Total Conveyance Area Changes by Station, March 2002 to May 2004 (Reach Channel Slopes in Blue)

Figure 5.2.92

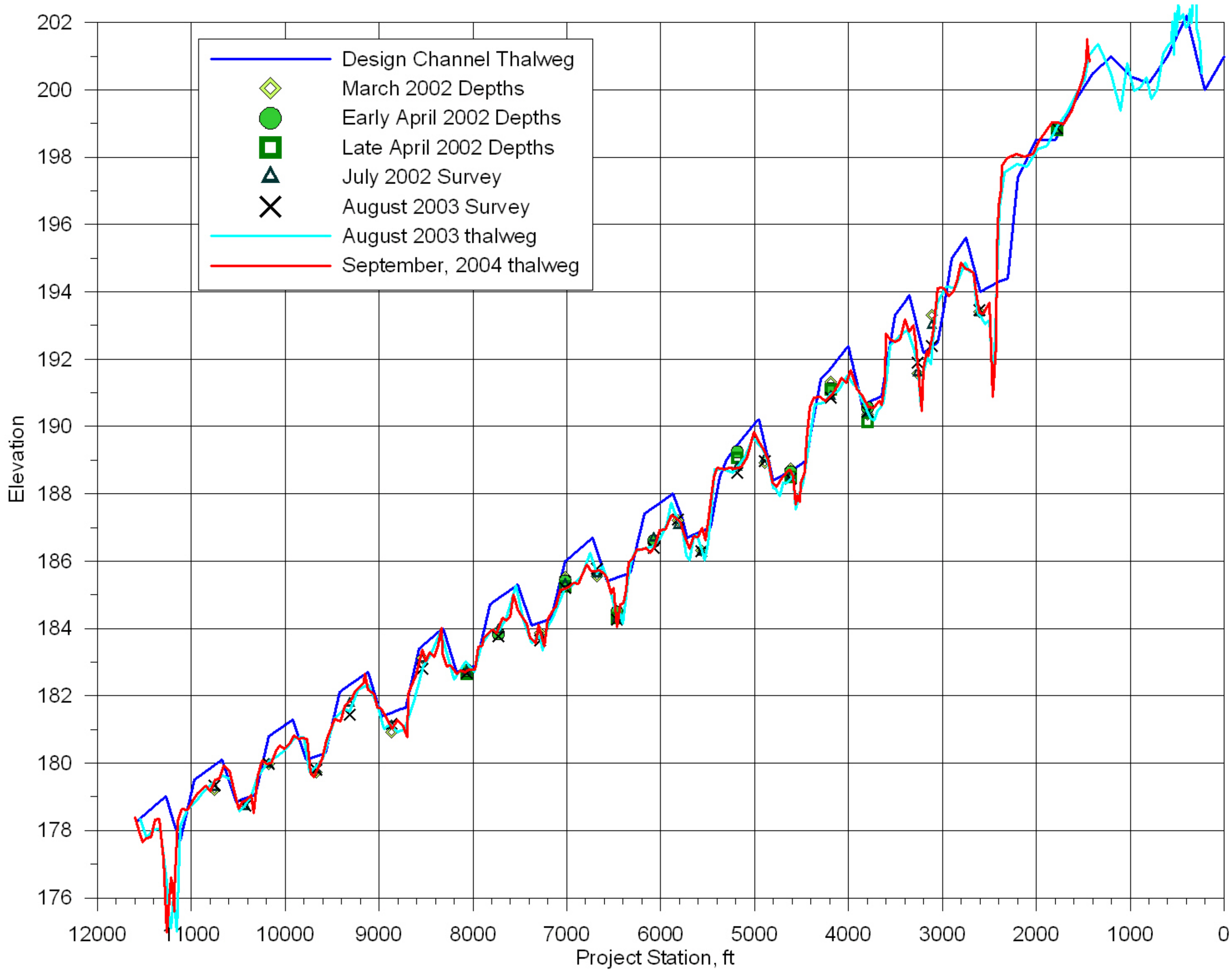


Figure 5.2.93. Thalweg Profiles

Figure 5.2.93

6 SUMMARY

6.1 Adaptive Management

Adaptive management is an iterative process resource managers can use to incorporate the problem solving power of the scientific method into ongoing management actions (Austiguy et al. 2003). In 2001, the Adaptive Management Forum (AMF) was initiated to provide advice on ways to incorporate adaptive management into river restoration projects already in various stages of implementation, including Phase III of the MRSHEP. Several recommendations came out of that effort, a few of which are directly applicable to this project's monitoring program. The recommendations include:

- Expanded use of Passive Adaptive Management, which could be implemented through quantitative expectations of river behavior tested by observations.
- Improve the linkage between physical and biological monitoring.
- Add staff and resources for monitoring activities.
- Coordinate monitoring programs between project teams.
- Monitor across project, reach, and tributary scales.

Although the AMF panel made these recommendations and others, they stated that the restoration teams should not feel bound to follow them, but do have an obligation to take the comments into account. The MRSHEP restoration team found the AMF process helpful and informative, and we intend to do our best to incorporate as many of the recommendations as possible into our projects. Several examples follow.

Passive adaptive management is currently being employed to develop improved monitoring and analysis procedures. While this report has been primarily aimed at reporting data collected over the two years following construction of the project, we hope to employ this data to improve and adapt our monitoring plans and our understanding of the processes acting on the reach. As a result of this improved understanding, we hope to improve future project designs and monitoring efforts. Recommendations later in the report will be aimed at adapting our monitoring program to focus on areas of the project that have shown to be providing the most information so far.

We hope to show improved linkage between physical and biological monitoring in future reports by including the elements of the monitoring plan like groundwater elevation monitoring that can be applied to revegetation success. We have included riffle and bar surveys in this report that can be related to salmon spawning in the reach.

We have been actively pursuing the addition of staff and resources for our monitoring activities of the reach. This includes additional funding for future activities and the addition of graduate students who are specializing in cutting edge studies related to river restoration. We have also been coordinating with universities for guidance and assistance in expanding and improving monitoring efforts.

6.2 Conclusions and Recommendations

Extensive monitoring activities performed since the completion of construction of the Robinson Reach project in early 2002 have produced a large amount of information about the reach. However, because flows did not exceed design bankfull for any significant amount of time during that period, no major changes in the channel were observed. Monitoring data has shown, though, several significant trends and characteristics of the channel's performance in that period of time.

6.2.1 Bed Mobility

While the Helley-Smith data presented should provide a basis for roughly estimating total sediment transport in the upper reach riffles of the Robinson Project site, it is too sparse in both the range of flows and in the number of samples collected at each flow and section to enable engineers to develop an accurate estimate of sediment transport in the reach. We recommend further measurements on two to three riffle sections in the future with at least 4 samples at each section and each flow to provide better transport rate profiles. Improved transport rate analysis will enable a sediment budget and maintenance plan to be developed for the reach that will give planners a better tool to more accurately plan future maintenance of the project.

Tracer gravel data was not collected at different stages of each flow event, so a graph of rock movement percentage vs. discharge could not be created to identify the incipient mobility range. However, the data we did collect in 2002 and 2003 showed significant movement of all size classes of tracer rocks for both years, with the frequency slightly higher in 2002. One conclusion we can reach from this data is that the bed appeared to be slightly more mobile during 2002 flows (1,400cfs) than during the 2003 flows (1,550cfs). The tracer data, the helley-smith samples, and the scour of the mean bed elevation of riffles in the upper reach in 2002 support the hypothesis that artificially placed gravels are more mobile than those that have been sorted by river processes. In conjunction with our graduate student assistants and UCSB researchers, we are currently applying mechanistically based models to explain the mobility of the bed immediately after construction.

6.2.2 Channel Shape and Gravel Bed Changes

Changes in the channel geometry were primarily recorded by the cross-sectional surveys taken at monitoring sections at various times over the monitoring period. Based on that data presented in Section 5.2.3 of this paper, it would appear that forces experienced in the channel during peak flows of 2002 (1,400cfs), 2003 (1,560cfs), and 2004 (1,840cfs) were not high enough to significantly reshape the channel planform. These peak flows were of relatively low magnitude, and this channel response was as expected for those flows. The flows did appear to be enough to affect the cross-sectional geometry of the channel in some areas, however. Particularly in the upstream half of the reach, some of the riffle sections showed some minor scour of the channel bed, but the most pronounced changes occurred at the upstream end of each bend, where flows deposited material on the inside of the bends to narrow the channel. Our survey data suggests that aggradation of point bars is occurring even in years when the riffle cross-sections are not changing (2003-2004). Additional whole channel survey data being currently analyzed will allow us to further examine aggradation trends on the point bars over time. Furthermore, the material depositing on the point bars is finer than the riffle material. These changes suggest that the pools are narrowing to increase their ability to transport the sediment delivered to them. But where is this material coming from? A corresponding fining of the riffles during the same time period (2002-2004) further suggests that material is coming from sources other than the riffles. The pools were originally designed to be somewhat wider than necessary for added stability while vegetation was established, and the design HEC-RAS model indicated low shears in the sections, so the deposition is not surprising. As the channel is augmented with gravel over the years, the pools will form their optimum channel geometry; a feature our monitoring efforts will document.

6.3 Hypotheses Revisited

As data was gathered and processed during the monitoring process, original hypotheses were revisited and new hypotheses developed. Below are hypotheses to be applied as additions or replacements to the list presented in Section 3.4.

- Channel complexity will increase over time from the baseline physical conditions through point bar growth, scour and deposition of riffles, bank erosion, lateral channel migration, and the development of a coarse surface layer. This hypothesis is a modification and replacement of the original hypothesis #1, and allows for a more specific and testable statement of what we expect to happen to the channel over time in the reach as a whole.

- The grain size distribution on the surface of riffles will coarsen over time. This hypothesis assumes no gravel augmentation will be executed on the site. Although pebble count results since 2002 initially showed a general fining of riffle gravels, later pebble counts showed modest increases in D_{50} for most riffles. We believe the more recent trend will continue in the absence of outside intervention.

7 FUTURE MONITORING PLANS

7.1 Future Monitoring Activities

In addition to addressing the hypotheses listed in the beginning of this report, there are additional questions we want to answer. A series of questions and the additional data that needs to be collected are presented here.

1. Are point bars developing in the downstream reaches (i.e. downstream of river station 63+70)? We have seen evidence of obvious point bar development in several of the upstream pools, but do not yet have data to show whether this is a trend throughout the reach.
   - Add one or more cross-sections to the head of at least one of the pools in the downstream reach not observed to have bar growth.

2. What is the size of the material depositing on the point bars? Initial data shows the D_{50} of deposited material is smaller than that of the material placed during construction. A more thorough analysis of these materials would help us determine sediment transport in the reach.
   - Perform pebble counts on the developing point bars with at least 100 grains measured on the bars.
   - Collect and analyze bulk samples of the bars using a McNeil sampler.

3. Are spawning-sized gravels being transported into the reach from upstream? Are they moving through the pools?
   - Collect bedload samples at the upstream-most riffle.
   - Collect bedload samples from a pool in the upstream portion of the reach.

4. Has an armor layer developed on the riffles?
   - Collect bulk samples using a McNeil sampler and perform pebble counts at the same sites.
   - Use freeze cores to examine vertical stratification.

5. Has the channel morphology changed in response to 2005 flows? Flows in early 2005 exceeded banks of the channel for a sustained period of time. Data will be needed to assess the response of the channel to those flows.
   - Perform a topographic survey of the channel before 2006 high flows.
   - Collect bulk samples of newly deposited material.

7.2 Future Data Analysis

The goal of all future data analysis is to develop a process-based understanding of the changes that have occurred in the Robinson Reach from construction to the present date in order to:

- Improve applied sediment transport theory for designing and managing future restoration projects on the Merced and beyond;

- Provide a sound science basis for future gravel augmentation on the Merced and beyond;

- Develop an understanding of how sediment transport and flow processes (e.g. bed load, shear stress) create and maintain the river channel and bed habitat (e.g. pools, riffles, point bars, cross-sectional shape, surface and subsurface bed material) and the hydraulic habitat (depth, velocity).

We are currently applying existing theoretical, mechanistic models to explain the changes we have seen in the Robinson Reach. We also hope to further our understanding by expanding our one-dimensional hydraulic and sediment transport calculations and by conducting two-dimensional hydrodynamic modeling of the reach. A better understanding of the relationship between shear stress, grain size on the bed, and bed material that is transported through the reach will help us manage the Robinson Reach as a dynamic river system that continuously creates and rejuvenates habitats at many scales. Last of all, we hope to use measured changes in channel morphology to obtain improved estimates of reach-scale sediment transport rates.

7.3 Future Experiments

Our data suggests that mechanically placed gravels may be more mobile than fluvially reworked gravels with the same grain size distribution. The mobility of mechanically placed gravels has implications for future gravel augmentation on the Merced. We would like to conduct a series of patch experiments to further test our preliminary findings. We propose to mechanically construct patches of loose material with the same grain size distribution as the surrounding bed. Furthermore, we would like to test the hypothesis that the local supply of fine bed load (e.g. fine gravels) influences the mobility of the bed with small scale experiments before performing a full blown gravel augmentation of the Robinson Reach.

This work will lead to our goal of establishing a long-term gravel augmentation plan that will be part of the overall maintenance program for the reach. Based on the data already gathered and data expected from future monitoring activities and experiments, we believe we can develop an augmentation scheme that will promote quasi-stability in the reach through material transport.

8 OTHER PROPOSED STUDIES

Other studies have been proposed by DWR for the Robinson Reach, in association with our continuing monitoring efforts and with the University of California, Santa Barbara, under a CALFED funding request in 2004. Included in the proposal were the following hypotheses and associated actions:

1. **Reach-scale bedload transport rates can be inferred from measurements of morphologic change**. Activities proposed for this hypothesis included high-resolution topographic surveys bracketing significant flows, pebble counts, tracer gravel, bedload samples and scour chains to characterize morphologic change.

2. **Spatial patterns and probability distributions of flow depth and velocity vary with discharge and can be used to characterize in-stream habitat.** Associated activities included obtaining coordinates of channel centerline from topographic survey or rectified aerial photography, and conducting spatially distributed measurements of flow depth and velocity at a range of discharges.

3. **Partial transport of mixed grain size sediment can be modeled using spatially varying probability distributions of critical and applied shear stress. This stochastic modeling framework can then be used to design and evaluate various gravel augmentation strategies.** Associated activities included obtaining spatially distributed grain size measurements from pebble counts and substrate photos, using microtopographic profiles obtained with a surface roughness template, collecting spatially distributed velocity profile measurements, and conducting a high-resolution topographic survey.

4. **Under immobile riverbed conditions, the ecologically relevant riverbed characteristics will degrade over time.** Associated activities included measurement and mapping of surface grain size distribution, measurement and mapping of patches of surface fine bed material and surface microtopography, and measurement of subsurface grain size distribution, hydraulic conductivity, and dissolved oxygen.

5. **Bankfull flows will flush fine bed material from the subsurface.** Associated activities were the same as for #4, plus measurement of depth of scour and deposition.

6. **The distribution of fines on the surface and in the subsurface can be predicted.** Associated activities included those of #4 and #5, plus installation of infiltration cans and measurement of infiltration rates, measure fine fraction of the bedload, suspended load measurement, velocity profile measurements, flow measurement, and surveying enough of the channel to model 2-D fluid dynamics.

7. **The quantity and distribution of fine bed material affects the mobility of the coarse gravel framework.** Activities used to evaluate this hypothesis are essentially the same as in #6.

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